

SAFETY CONSIDERATIONS IN THE CONDUCT OF COLLEGE  
ELECTRICAL ENGINEERING LABORATORIES WITH  
PARTICULAR REFERENCE TO THE LABORATORY COURSE  
FOR NON-ELECTRICAL ENGINEERING STUDENTS

A THESIS

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Master of Science

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Introduction

Accident Prevention Through Integrated  
Materials and Activities

In the past engineering colleges have tried to offer the student, in exchange for four years of intensive study, a sound theoretical background in the field of his choice. The superficial insight into the practical requirements of an engineering position in industry were gleaned indirectly from his association with the college laboratory and the experiments he performed therein. While these experiments were designed primarily to illustrate the theoretical principles promulgated in the class room, nevertheless the student became familiar with the machines by actually working with them. This familiarity might be construed, to a limited extent, as practical experience.

Since the long range trends in engineering education are dictated by the needs of industry, the curriculum in many engineering colleges has changed gradually during the past two decades in such a way as to accentuate the practical side of engineering and thus to better adapt the embryo

engineer for the transition from college to industry. Whether this gradual modification is accomplishing the desired end or not is a subject of some controversy among educators, and is not within the scope of this paper.

One of the subjects receiving more attention than ever in this period of change is the subject of safety in industry. Many engineering colleges are offering undergraduate courses in industrial safety and a few are offering courses at the graduate level; however, many authorities believe that safety can be taught more effectively by integrating the principles of safety into the engineering texts.

The writer suggests that both are necessary, but that the integration theory should be extended to encompass the teaching staff and the laboratory as well. The following pages will be devoted to an attempt to justify this belief by setting up a representative and workable safety program for a college laboratory, using safety integration where feasible.

The electrical engineering laboratory has been chosen and the course considered is the laboratory course offered to students other than those majoring in electrical engineering. Experiments from the laboratory manuals of several large engineering schools have been selected for analysis.<sup>1</sup>

The subsequent material will be presented in three sections. First, the laboratory and the equipment; second, instructor training; and third, the laboratory manual itself will be considered.

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Chapter I

SAFETY CONSIDERATIONS - LABORATORY AND EQUIPMENT

The primary purpose from a safety point of view in establishing a laboratory should be to provide a safe working place with safe equipment. Any attempt to analyze methods and procedures, or in any manner to regulate the student's actions in the laboratory, as a means of preventing injury, without first providing a safe working environment for the student, is likely to prove fruitless.

Observance of the Prevailing Electrical Codes

All wiring in the laboratory should be in accordance with prevailing standard practices. If a local code is in force it should be met scrupulously and in every detail. In no event should any wiring or installation be less than that allowed by the National Electrical Code.

It is realized that most codes, the National Electrical Code included, do not offer regulations governing laboratories specifically; however, it is felt that these codes can serve as guides - as absolute minimum standards which should always be met and usually exceeded. Often wiring problems



will arise that are unique to laboratory installations. It is here that care must be exercised to provide wiring that would meet the most critical inspection. An extrapolation of the prevailing code can be effected in some cases to provide a basis for action.

Since the primary purpose of a laboratory is to provide a place of learning, it is of paramount importance that the examples provided be correct and safe in every detail. It is true that the laboratory course is designed to teach the student through the performance of experiments; however, he learns also from his observations of laboratory equipment and installations other than those used in his experiments. Any such installations he will assume to be correct and in compliance with the latest codes and practices. For this reason it is necessary that wiring not only be installed correctly, but should be reviewed periodically to see that no serious violations have been caused by code revisions subsequent to the original installation.

At the time of installation equipment should be selected that is most representative of the best and newest offered to industry. While some of the equipment should be older to give the proper cross section of equipment in industry, it is believed that the problem here will be that of maintaining a laboratory that adequately reflects the recent trends in electrical equipment.

### Floor Loads

All moving machinery and heavy equipment should be mounted permanently to the floor. It is assumed that the load bearing capacity of the laboratory floor is adequate; however, in some of the older buildings, or buildings designed for other purposes, this capacity should be checked prior to the addition of equipment or the shifting of existing equipment. Too often on the college campus a building will be designed for one specific department, but over a period of years will be used for several other departments and purposes. Therefore, while the floor bearing capacity may have been adequate to support the load for which it was designed, it may be entirely inadequate for the load it is now carrying.

### Guarding of Moving Machinery

Adequate guarding of moving machinery, a practice often neglected in school laboratories, should be carefully considered. Standard guards, such as are offered on the commercial market, can be used to advantage to enclose pulleys, belt drives and the like. These guards could be used without modification on machinery not actually used by the student.

It is desirable, in order to make the task of learning easier, that visibility and often accessibility to moving parts be provided. In such cases the use of guards made wholly or partly of transparent plastic can be used. Small hinged openings can be provided where accessibility is

necessary, or perhaps a small hole, such as would be required to allow entry of the speed counter to the shaft end of an electric motor could be made. In other instances a commercial guard might be modified with plastic windows and hinged openings to serve adequately.

It will be necessary that most of these guards be removable for maintenance, and perhaps some of them will require removal during the course of an experiment. In instances where the exposure would be especially hazardous, or would expose a number of people as it would in the latter case, it is recommended that switches be installed which will prevent operation of the machine while the guard is removed or improperly placed in the protective position.

Since most of the guards will have to be constructed or modified to the particular requirements of the machine with which they are to be used, a careful study of each machine should be made and its hazards listed. From an appraisal of this study a satisfactory guard can be devised. It is suggested that the services of the safety department be solicited for aid in this undertaking, if the college has such a department. If not, the local safety council or the local chapter of the American Society of Safety Engineers will help. The machine shop, the sheet metal shop and the woodworking shop can be helpful in the construction or modification of the guards.

### Contact With Live Circuits

In addition to guarding against injury by contact with moving parts, it is important that consideration be given to the possibility of injury by contact with working voltages. While the average layman, as well as engineer, tends to minimize the hazards associated with voltages of 220 volts or less, cases are on record of fatalities resulting from contact with voltages of less than 50 volts, alternating current. Also the involuntary muscular contraction resulting from contact with low voltages can contribute to falls or contact with moving machinery.<sup>2</sup>

A careful study of the entire laboratory should be made to uncover and guard against points of accidental contact with live circuits. For example, a rubber mat might be placed in front of the main switchboard, particularly if the switchboard is not the "dead front" type. This mat should be extended behind the switchboard if anyone goes there regularly to change connections.

### Warning Signs

In places where some degree of hazard exists that cannot be guarded against adequately, the use of warning signs should be considered. It is important that these signs be few in number and carefully worded to avoid exaggeration of the hazard. It is a rather common practice to overemphasize danger in an attempt to secure greater caution. The result of this practice is often the opposite of that desired; because once a reader finds that a sign is

exaggerated, he doubts the accuracy of all signs in that area. Also the use of too many signs promotes the tendency to disregard them all.

The greatest danger in the use of signs, however, is the tendency to use a sign where guarding would be expensive, difficult, or inconvenient. The most important rule to follow in the use of warning signs is - "Never use a sign in lieu of a guard."

#### First Aid Fire Equipment

Since the majority of equipment under consideration would be electrical in nature, fire extinguishers should be provided that are approved for use on Class C fires. Among those most suited for this type of fire are carbon dioxide, vaporizing liquid, or dry powder extinguishers.<sup>3</sup>

The fire hazard to be considered here is somewhat different from that normally encountered in industry. Each machine in the laboratory is under constant surveillance while running; consequently, any fire starting in the electrical equipment under test would be detected at its inception. For this reason it is suggested that a one quart vaporizing liquid extinguisher be located within 10 feet of each experiment station. The additional protection required can be provided in the form of larger carbon dioxide extinguishers strategically located both from a standpoint of proper spacing and proximity to specific hazards. For example, one of these extinguishers should be located near the main power board.

The units of first aid fire protection required are determined by the occupancy classification of the building, and this classification will vary somewhat in different laboratories; however, classification will always be either Class II, moderate hazard occupancy, or Class III, high hazard occupancy.<sup>4</sup> In order to secure an accurate and authoritative determination of the degree of fire protection required, a consultation with the local fire marshal is suggested. If any doubt as to classification exists, the high hazard classification should be selected, particularly if class rooms are located above the laboratory. In all cases it is probable that the units of first aid fire protection required for the floor housing the laboratory will be greater than for the other floors which contain class rooms only.

A sprinkler system is desirable, as is also true for all other buildings on the campus; however, the type to be used, the spacing of sprinkler heads, and the other necessary considerations are beyond the scope of this paper.

#### First Aid Medical Equipment

In many electrical engineering laboratories one first aid medical kit is sufficient. It should be placed in a central location where it is quickly accessible in an emergency. If the laboratory is unusually large or occupies more than one floor, the provision of additional kits will be necessary.

At least one person who is in the laboratory during

its entire period of use should have first aid training, with special emphasis on the treatment of burns and the application of prone pressure resuscitation. The stock room custodian or the maintenance man would likely meet the conditions of constant laboratory attendance.

### Lighting

The necessity of adequate lighting is highly important, yet it is often neglected. One explanation for this neglect is that the human eye quickly adjusts itself to the light intensity available, and often persons working under too little light are unaware of its inadequacy. Whether the eye is permanently damaged by working in slightly substandard light is a subject of controversy; however, that this condition enhances the possibilities of an accident is generally accepted by safety engineers.

The use of combined fluorescent and incandescent lighting is recommended for the entire laboratory. All fluorescent tubes should be "paired" to preclude the possibility of stroboscopic effect with the moving machinery. Prevention of this phenomena also requires close maintenance to insure that burned out tubes are promptly replaced.

The supplementary use of incandescent illumination is recommended to "balance" the fluorescent light. Many persons feel that fluorescent lighting quickly tires their eyes. While this may be partly due to imagination, the

end result is the same. A person who thinks he is tired is more inclined to have accidents than one who is rested. It has been found that the use of incandescent lights in approximately the ratio of one to three will materially reduce the objection to fluorescent lighting, and for this reason, the use of combined lighting is recommended.<sup>5</sup> It is a rather common practice in industry to use fluorescent tubes for general lighting and incandescent lights for local lighting. This arrangement seems to give good results.

Light readings should be taken throughout the laboratory with particular care being given to each experiment station. Then the illumination system should be designed to give adequate general lighting, and intensities at work stations sufficient for work of moderate closeness. Twenty foot-candles is recommended for the stations, while ten foot-candles or less can be provided for the general lighting.<sup>6</sup> If no one in the college faculty is qualified for this work, the services of a commercial lighting engineer should be sought. The large electric manufacturing companies will be glad to furnish an engineer for this purpose free of charge.

A major portion of the problem of proper illumination will be that of the elimination of direct and reflected glare. While glare of any type tends to cause eye strain and fatigue, it is also often a contributing factor to industrial accidents. The elimination of direct glare is a design function and may be accomplished by indirect or semi-direct lighting, and by locating the lights high enough



above the working surface.

### Painting - The Standard Color Code

The elimination of reflected glare can be effected through the proper use of paints. Smooth or slick surfaces are the major offenders in reflecting light in sufficient concentrations to produce glare; therefore, the use of high gloss paint should be restricted to the ceiling or other places not in a normal line of vision. The use of semi-gloss, and in some cases flat paint for equipment is usually the best, particularly in the case of moving machinery where the possibility of injury is imminent.

While painting can be used to advantage in glare reduction, it can also be of considerable value in the proper distribution of light.<sup>7</sup> The use of light colors on the ceiling and walls aids materially in distributing light through reflection. From 50% to 100% of the light may be diverted toward the ceiling in the case of indirect or semi-direct lighting; hence, in these instances it would be highly important that the ceiling be an adequate reflecting medium. Painting walls and equipment light colors also tends to eliminate shadows in the working area.

The standard color code should be used.<sup>8</sup> Red should be used to mark fire extinguisher locations, and the more dangerous locations in the laboratory could be brought to the attention of the students by the proper use of this code. In this connection it is thought to be helpful to use the

color code in painting guarded hazards a warning color, so that when the guard is removed the warning color is exposed. This makes the absence of a guard quickly noticeable, even from a distance.

### Maintenance and Inspection

The problems of maintenance and inspection of the laboratory are generally similar to those encountered in industry. It is suggested that a safety committee be organized for the purpose of making inspections and recommendations. This committee should consist of one or more laboratory instructors, and some consideration might be given to the inclusion of students. However, since the instructors should have had some safety training, it is advisable that one of them be appointed committee chairman. It should be the duty of this committee to make periodic inspections of the laboratory to examine laboratory equipment, machine guards, first aid fire equipment, and the like for wear, breakage, or other unsafe conditions. The personnel comprising the committee should be rotated often, perhaps monthly.

Conditions requiring routine maintenance and repair can be referred directly to the maintenance man in an informal note. Findings that will involve some expense will, in all probability, have to be written into a report and submitted to the department head for action.

Action should be taken promptly on all recommendations. The maintenance man should be informed as to who is chairman

of the committee at all times, and should understand that any committee finding bearing his signature should be corrected without delay. The department head should know that prompt action on his part with regard to reports referred to him is entirely necessary, or the committee will be rendered impotent.

Where some delay will be involved in the correction of a hazardous condition, the use of warning signs, temporary guards, or complete abstinence of use of the equipment involved should be resorted to, depending on the nature and extent of the hazard.

Each instructor should supplement the committee inspections by reporting conditions requiring maintenance or repair which he notes during his normal tour of duty in the laboratory. It should be explained to the student that any such conditions which he notices during his use of the laboratory should be referred to his instructor immediately. Because of his close association with the equipment, the student can discover conditions not readily perceptible to the instructor. This practice of requesting assistance from the student would not only tend to stimulate student interest, but would also be helpful in the discovery of hazards not detected by the instructor.

The stock room man, in all probability, is required to examine each item of equipment turned in to him by the student to see if any damage has been incurred during use. Items requiring repair, however, should be carefully separated from the regular stock until repair has been effected.

A special section should be provided in the stock room for damaged equipment.

### Housekeeping

The housekeeping problem is not as extensive in the laboratory as it is in industry, because in the laboratory there is no production to produce waste; however, there are some factors of housekeeping that require consideration.

Since all illumination systems depend to some extent on reflected light, the condition of the wall surface must be considered. Proper lighting design provides approximately 25% more lighting than is required to meet standard to allow for gradual accumulation of dirt on the walls. Where this dirt accumulation takes place very slowly, the gradual change in wall appearance is not usually perceptible to one who works there day after day, nor is the gradual decrease in lighting intensity which accompanies it. For this reason it is advisable to make periodic checks in the laboratory with a light meter to be sure that the light reaching the working areas is sufficient. If not, cleaning of the walls should be considered as a remedy.

There is always a possibility of oil dripping on the floor wherever there is moving machinery, although, admittedly, the amounts would usually be greater in the case of internal combustion or steam powered engines. It takes only a small oil spot to create a hazardous condition however, and the fact that it does not occur in copious quantities fosters a tendency to ignore the dripping that might occur.

Since drip pans are not usually necessary, the provision of an oil absorbent to be sprinkled on the occasional oil spots that occur would be advisable.

There is usually a good chance of having appreciable quantities of water on the floor, particularly when prony brake tests are being made. Water, being used as a coolant in the rotating pulley, is usually spilled around the machine. Here the use of specially designed drip pans and a great deal of care are required to keep it off the floor. The water spilled should be removed immediately, since the hazard is not only one of providing unsure footing, but also one of increasing the severity of possible electrical shock by providing a better ground connection and by lowering the skin resistance of the body. Standing in water could cause what would otherwise be a light shock to be fatal.

Most laboratories have portable equipment that is either carried or is mounted on a table or stand equipped with casters. In laying out work stations, space should always be provided for this equipment so that it will not block aisles. The proper location of the larger portable caster mounted equipment might be indicated at each work station by stencilling on the floor. Particular care should be taken to insure that a free path will be available at all times to all fire extinguishers and exits, and students should be instructed to place portable equipment so that it will not obstruct these passages.

A set of a few concise rules for the student to follow would materially aid in maintaining an orderly laboratory.

## Chapter II

### INSTRUCTOR TRAINING

#### Suggested Course of Study

It is axiomatic that satisfactory presentation of a course cannot be realized when the instructor does not have a working knowledge of the subject to be taught, or when his thinking on the subject is confused. When such a condition exists, the preparation of lectures is an arduous task and any questions asked by the students which do not follow strictly the lines along which the lecture has been prepared, are not likely to be answered adequately.

Where the course is a laboratory one, more questions are likely to be asked, and these questions also tend to be more varied in nature. Therefore the laboratory magnifies the factors which require the thorough grounding of an instructor in his subject.

Since the statements above are self evident with regard to the principal subject taught, it appears that the same approach in thinking should apply to a supplementary subject, particularly when an attempt is being made to integrate this latter subject into the presentation of the former.

To provide the background that is necessary for safety instruction, it appears that some formal education concerning this subject should be provided for those who are to teach it. Consequently, it is felt that the success of a

safety program in the laboratory will be hinged to a great extent on an adequate teaching course for the instructors.

Obviously it would be impractical, and undesirable, to attempt to devise an instructor training course that would make each instructor a safety specialist upon its completion. The most that can be hoped for is a short concentrated course in safety, especially prepared to give the instructor a brief, overall picture of the industrial safety conditions and practices as they currently exist, and to stimulate his interest toward further reading and study in that direction. A suggested course of study for such safety training follows:

<u>Monday</u> - Industrial Safety	Cover generally industrial safety and its importance - the extent of its applications in industry today, the attitude of management toward safety, etc. This should be followed with a discussion of the safety considerations in electrical installations.
<u>Tuesday</u> & - Machine safeguarding	Use of commercially available safeguards - extent of safeguarding in industry today, how to select proper safeguards for specific machines. Use of numerous illustrations and possibly a field trip is recommended.
<u>Wednesday</u>	
<u>Thursday</u> & - Fire Control	First aid fire equipment - maintenance and use of extinguishers. Here demonstrations of the use of extinguishers suitable for Class C
<u>Friday</u>	



fires, and actual use of each type by those taking the course, is recommended.

<u>Monday</u> & - Methods Analysis	Analyze simple industrial operations to incorporate safety into the procedures -
<u>Tuesday</u>	apply these principles of analysis to laboratory experiments.
<u>Wednesday</u> & - Safety Committees and Inspections	Organization and Operation of safety committees -
<u>Thursday</u>	conduct of inspections and the use of check lists - making reports and recommendations, etc.
<u>Friday</u> - Discussion	Give typical examples of hazardous conditions that might occur in the laboratory and discuss how they might be handled - give specific information that is to be integrated into a lecture and discuss the best method of doing this, etc.

The presentation of the foregoing schedule should be generally slanted toward the problems and hazards normally encountered in electrical equipment in industry, with more specific references to the electrical laboratory itself. Since this short course can only give sketchy coverage to the subjects involved, it is important that a carefully prepared bibliography be presented, arranged according to subject.

The choice of instructor, or instructors, for the course is important, primarily because he must be able to give a well organized, lucid presentation of the subject, and because he must be able to invoke an interest in his

listeners that will prevail beyond the end of the course. In this connection, it is desirable that the department head attend as many lectures as possible, because his active interest and cooperation will be directly reflected in the degree of effectiveness attained by the safety program.

#### Importance of Good Examples

Instructor interest must be not only created, but also maintained. Faithful adherence of the instructors to safe practices in the laboratory is of more importance than the accident prevention work they teach. Students, for the first time in the strange new environment of the laboratory, naturally look to the instructor for advice and guidance. The instructor's attitude and behavior in the presence of working voltages and rotating machinery is closely watched and often adopted by the student. Short cuts taken by the instructor at the expense of safety can adversely affect the entire laboratory safety program.

#### Gaining Experience in Safety Work

Any course of study, such as the one discussed, no matter how complete its coverage of the subject, leaves many questions in the minds of the students. Most of these questions are concerned with the manner in which the principles they have learned in class are put to practical use. The best way to resolve these questions seems to be by observation of the operation of safety organizations within industry, and perhaps participation in industrial safety work.

In this connection, working arrangements can be made with local industrial establishments for the instructors to make plant visits and discuss the plant safety program with the safety director. Perhaps it might be possible to "sit in" on some safety committee meetings to see just how they are conducted and what business transpires. The visits should be made in very small groups for greatest benefit, one or two men constituting the best group size.

Additional arrangements can be made with industries to employ instructors during the summer months to work in their safety departments. Experience of this type is invaluable in making a college laboratory safety program work.

#### First Aid Training

Instructors should be encouraged strongly to acquire some first aid training. The basic Red Cross first aid course or its equivalent is recommended. In the event that such formal training is not available, it is suggested that the Red Cross First Aid Book or its equivalent be procured, and informal classes conducted on prone pressure resuscitation, the treatment of burns, and the treatment of severe bleeding and fractures.

## Chapter III

## THE LABORATORY MANUAL

The first part of this paper has covered briefly the physical considerations in the laboratory as a necessary adjunct to the provision of a safe working environment.

It is altogether proper that they be considered first since no adequate safety program can be constructed until the tools and working place provided are designed to permit their safe use.

Following this was the consideration of instructor training which is also a very necessary component of the safety picture. As was indicated in the discussion, safe practices cannot be presented adequately to the students until the personnel responsible for the presentation have a working knowledge of accident and fire prevention.

Finally, it is felt that the instructor, upon completion of his initial training period, should have at his disposal, a text designed to aid him in accident prevention work; that is, a text which has incorporated the fundamental aspects of safety into its content. The provision of such a text is the purpose of this final section.

A number of college laboratory manuals have been studied, and experiments which are considered representative have been selected. These have been rewritten for the purpose of integrating the necessary safety material into the texts.

The experiments have been written in such a manner

as to allow their use in the college laboratory without change. An attempt has been made to present the experiments in such a form as to allow their separation from the text for use individually with a minimum of change. For this reason, many precautions are repeated in experiment after experiment. If the experiments are to be used as a unit, it is felt that the repetition will not endanger the cause of safety, since repetition is a good teacher.

Where safety considerations are present which do not lend themselves readily to their inclusion in the text by reason of their nature or their length, they have been included in a commentary at the end of each experiment.

In order that the student be made cognizant of the considerations mentioned above, it is felt that they should be discussed with the students prior to the laboratory period in which the experiment is to be performed. Since most college laboratory courses have a pre-laboratory period in which the next experiment to be performed is outlined, the inclusion of safety in this discussion should be relatively simple to arrange.

Because the safety considerations in the written experiments are brief, these should be expanded during the pre-laboratory session. The instructor should take care to explain how the safety aspects of the experiment tie in with its performance; in other words, why the written instructions specify that a certain job be performed in a certain sequence.

In the initial discussion period, it would be well for the instructor to point out the effects of low voltages on the human body, and how easily they can produce serious or fatal results.<sup>9</sup>

## Experiment No. 1

### A Study of Grids, Switches, and Various Meters

Object: The object of this experiment is to become familiar with the proper use of grids (resistance loading units), switches, ammeters, voltmeters, and wattmeters in order to avoid instrument and equipment damage and personal injury.

Test Equipment: Two single pole-single throw switches, two double pole-single throw switches; one double pole-double throw switch; three grids (resistance load units); one D. C. voltmeter, 0-150 volts; one D. C. ammeter, 0-50 amperes; one A. C. voltmeter, 0-150 volts; one A. C. ammeter, 0-5 amperes; one wattmeter, 750 watts; and one current transformer for use with the A. C. ammeter and wattmeter.

Procedure: (Read through entirely before starting.)

Connect the test equipment as shown in Figure E-1. Arrange the instruments and equipment so as to keep connection points and leads out of the working area. This is highly important, especially where connections are carrying heavy working currents or are bare.

This "hookup" should be wired from the "bottom up"; that is, starting with the grids and connecting to switches A and B last. In this way, the danger of contacting live voltages while connecting the equipment is minimized. The A. C. and D. C. lines should be connected to the jaws of their respective line switches, A and B. This practice also

minimizes the possibility of shock.

The single pole-single throw switches are used to short the ammeters and wattmeter when there is danger of excessive currents or when these meters are deflected in the reverse direction. These switches should be closed when the line switches are being closed, when the meters are not being read, and particularly when heavy current adjustments are being made or the meter leads are being handled in any manner. Switches A, B, and C should be left open until the connections have been checked by the instructor before starting the first run.

Grids consist of resistance coils connected as shown in figure E-1, and are normally used for loading generators or transformers by dissipating electrical energy in the form of heat energy. By throwing switch #1 on the grid to the right or left and switch #8 in the opposite direction (which puts all the resistance steps in series across the line), the lowest possible current drain is obtained. By throwing all the grid switches alternately right and left (which puts the resistance steps in parallel across the line), maximum current drain will be obtained. Additional capacity and/or finer current adjustment is gained by connecting more than one grid in parallel, as has been done in this case.

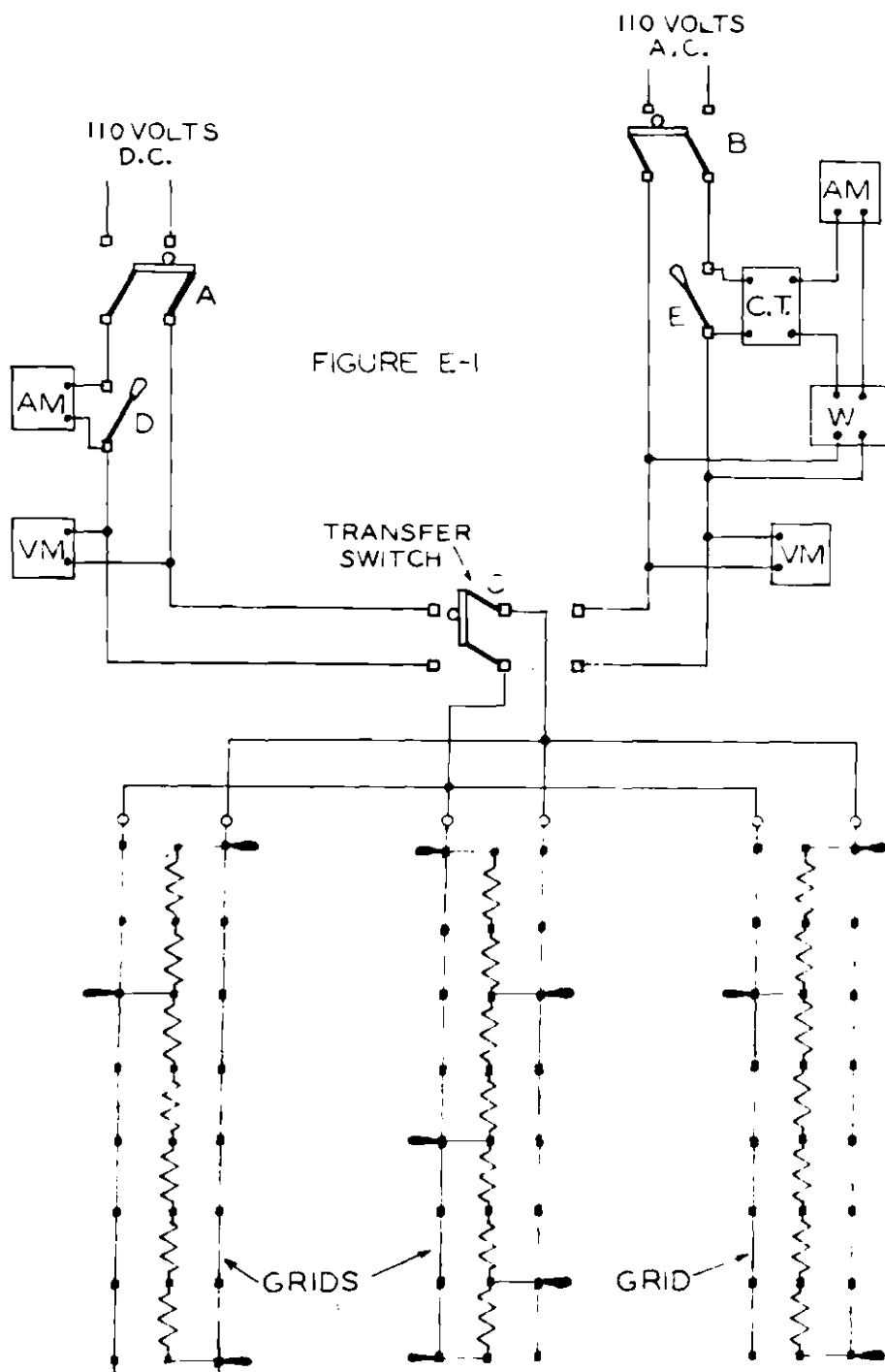
Care should be exercised in opening and closing switches. When closing a circuit, first be sure that you want it closed, then close the switch quickly and positively. Opening circuits carrying a heavy load can be dangerous



because of the likelihood of arcing, and the same procedure should be followed as in closing. However, the load should be reduced before opening the main switch, except under emergency conditions when immediate interruption of the circuit is necessary.

Meters are delicate, precision instruments and should never be dropped, jarred, or subjected to vibration. The ammeter is used with a shunt which passes most of the current around the instrument, the shunt being connected in series with the line. Most of the meters have built-in, permanently connected shunts, but a few use separate shunts. Carefully ascertain which type you are using since more than a few milliamperes passing through the meter coil is likely to cause permanent damage. The voltmeter has a high resistance in series with the meter coil, hence it is connected across the line. The wattmeter combines the operation of the voltmeter and the ammeter, and has two meter coils; therefore, precautions applying to either of these two will also apply to the wattmeter. The wattmeter reads true power when used on A. C., where the true power =  $EI\cos\theta$ . This means that a power reading with a low power factor could have either a voltage or current present that exceeds the capacity of the meter, and yet have a power reading that is on scale. For this reason, the current and voltage of every circuit should be checked before a wattmeter is used. Use an ammeter having a scale of the same range as the current coil in the wattmeter.

## EXPERIMENT NO. I



### Run I - Application of a Load Using Direct Current

After the circuit has been checked by the instructor be sure all grid switches are open and all meter shorting switches are closed; then close the transfer switch C to the D.C. side. Now close the D.C. line switch and check the voltmeter for polarity. Introduce a small grid load and open the ammeter shorting switches momentarily to see if the meters are reading up scale. If not, open the grid switches and the line switch in that order before reversing the meter leads.

Set the grid switches so as to get ammeter readings from 0-35 amperes in 2.5 ampere steps. Although the voltage should remain constant, record it at each step so that a record will be obtained if a variation should occur. When the run is completed, open all grid switches and the line switch A.

### Run II Application of a Load Using Alternating Current

Throw the transfer switch C to the A.C. side, and repeat the run, recording I, V, and W. Be sure to change the ratio on the current transformer to keep the ammeter on scale and to protect the wattmeter.

Report: Calculate the power expended for each set of readings for both the A.C. and D.C. runs. Compare these values with each other and also with the wattmeter readings taken in the A.C. run.

Draw sketches and explain briefly the operation of each instrument used. Outline the precautions to be observed in the use of each instrument. Give all the rules you can think of that should be observed in the use of switches. Explain briefly why each rule should apply.

Explain in detail why Figure E-1 should be wired from the "bottom up" as was directed in the procedure.

Can you suggest any precautions that might make this experiment safer?

Comments: This first experiment is designed to introduce the student to basic laboratory equipment and to instruct him in its safe use. Switches, for example, are used often in laboratory work, yet knowledge of their safe handling is usually gained by experience. This "experience" often entails a shock or burn from an arc and can be an expensive teacher.

By a logical and fairly detailed arrangement of the procedure set forth in the experiment, and by the use of precautions, an attempt has been made to integrate the following rules of safety into the performance of the experiment:

(1) A switch carrying a heavy current should never be opened if it can be avoided. This was emphasized in the procedure when the removal of the grid was specified prior to the opening of the line or transfer switches.

(2) Connections or changes on live circuits or potentially live circuits should never be made unless absolutely necessary. This rule was utilized in the procedure when it was specified that the proper order of wiring was to connect the equipment to the line last.

(3) When a connection change is made by the use of switches, the "dead" switches should be closed first, so that the closing of only one live switch will be required. Conversely, the live switch nearest the source of power should be opened first. This principle is demonstrated in the procedure outlined for the manipulation of the transfer and line switches.

(4) A circuit should never be "tested" by closing the switch until contact is barely made to see what happens. Instead, connections should be checked until it is certain that the "hookup" is the desired one; then close the switch quickly and positively. Before closing any line switch, however, be sure that the line is protected by a fuse or circuit breaker.

(5) The limitations of your measuring instruments should be understood thoroughly, and the steps necessary to protect them should always be taken. While this rule may seem designed primarily for instrument protection, actually it also has a sound motive of personal protection. It is quite easy to contact live circuits or moving machinery accidentally in a hurried attempt to rescue an instrument exposed to damaging conditions.

(6) The eyes should be shielded or averted when it is known that a switch is going to arc. The harmful rays produced by the arc can readily burn the eyes. Direct current has a greater tendency to sustain an arc than alternating current.

## Experiment No. 2

Characteristics of Shunt and Compound Motors

Object: To determine the load characteristics of shunt and compound direct current motors, using the prony brake as a loading device.

Apparatus to be Tested: 5 H.P., 120 volt direct current motor.

Test Equipment: Prony brake; one D.C. ammeter, 0-50 amperes; one D.C. ammeter, 0-10 amperes; one D.C. voltmeter, 0-150 volts; one speed counter.

Procedure: (Read through entirely before starting.)

A prony brake will be used to load the motor as well as to measure the output. It consists of an adjustable clamp to be clamped around the motor pulley, and an arm which is fastened to a spring balance to measure the pull of the motor. By multiplying the reading of the spring balance by the length of the prony brake arm, the torque is determined. See Figure 2-E(d), which is a sketch of the prony brake.

The motor pulley is filled with water (and kept full) after starting the motor to aid in dissipating the heat generated by the friction between the clamp and the pulley. Care must be taken that too much water is not introduced causing an overflow, because a wet brake is erratic and hazardous in operation. A drip pan should be provided,

because the water held inside the pulley by centrifugal force will spill out when the motor is stopped. Since this water is hot, particularly after a long run, observers should stand well away from the motor while it is stopping. The adjusting screws on the prony brake clamp should be loosened before stopping the motor to avoid a sudden stop which would throw hot water for some distance. One man should be assigned the job of operating the line switch and the prony brake. It will be his responsibility to check to be sure the clamps are loose each time before opening the line switch. If, at any time during the experiment the load becomes excessive and causes the line circuit breaker to open, a sudden stop is likely to occur. For this reason, if you should hear a breaker open, step back ten or fifteen feet quickly.

The use of the stirrup shown in Figure -2-E(D) reduces the possibility of equipment damage or personal injury in case of reversal of direction of the motor or any other occurrence which would throw the brake arm around violently. The arm stop which is just above the position of the prony brake arm would stop the arm in the case cited. The lower stop protects against a swing in the other direction.

At standstill the D.C. motor generates no back e.m.f. to limit the current flow through the armature. For this reason, it is necessary to limit the starting current to a safe value by the insertion of a resistance in series with the armature circuit. This is the function of the four



# EXPERIMENT NO.2

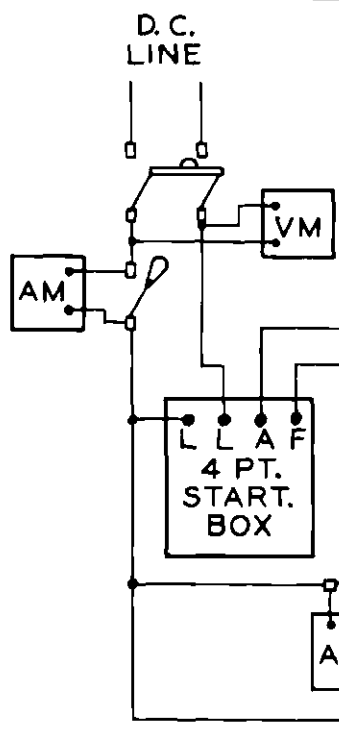
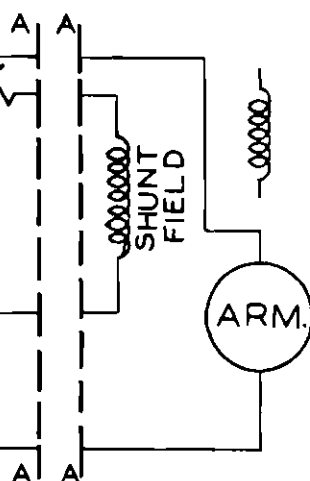
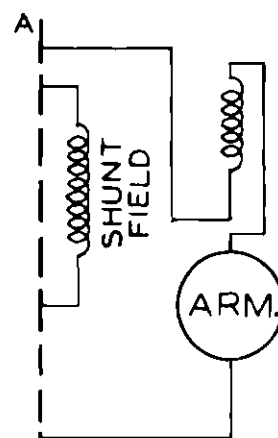
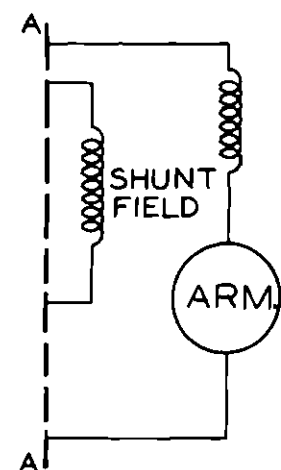
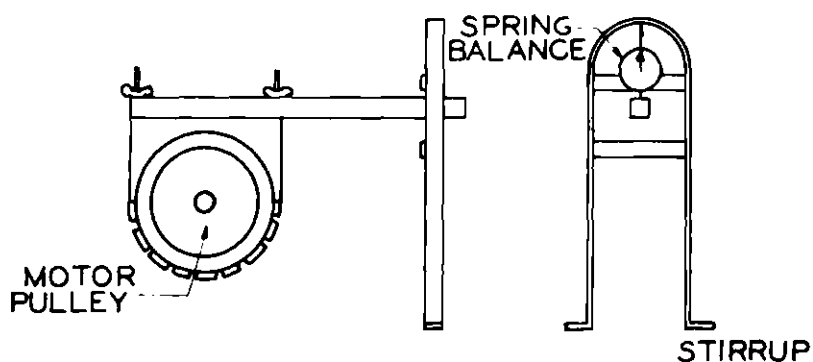


FIG. 2E

SHUNT  
FIG. 2E (A)DIFF. COMPOUND  
FIG. 2E (B)CUM. COMPOUND  
FIG. 2E (C)PRONY BRAKE  
FIG. 2E (D)

point starting box.

### Run I - Shunt Motor

Connect the motor as shown in Figures 2-E and 2-E (A) and have the instructor check your connections. Be sure all connections are tight, particularly the field connections. Before attaching the prony brake, start the motor as follows: With the ammeter shorting switch closed and all resistance cut out of the field circuit, place the starter on the first contact and close the line switch. If the motor does not start, open the switch and check your connections. If the motor does start, slowly cut out the starting resistance until the starter arm is in the running position. Note how the arm is held in this position. Open the ammeter shorting switches momentarily to see if the meter deflection is in the proper direction. If not, open the line switch and reverse the meter leads. Then start the motor as before.

The line voltage should be within three volts of the rated value of the motor. If it is not, ask the instructor to adjust it as necessary. Reduce the field strength by putting about half of the field rheostat resistance in the circuit. Take a set of readings, and after noting the direction of rotation, stop the motor. Do this by opening the line switch, never by using the starter arm, because the latter method is likely to damage the starting box.

Place the prony brake arm in place on the pulley with the clamps loose, first being sure that the direction of rotation is correct to make the brake pull down on the scales. If the direction of rotation isn't correct, the brake arm

will swing upward against the arm stop and may damage the spring balance or cause injury to an observer. Because the arm stops have been provided as a safeguard does not mean that they should be relied upon entirely to prevent injuries from this type of accident.

If the direction of rotation isn't correct, change the motor connections as necessary to reverse the direction of rotation. Start the motor and fill the pulley with water. Have your instructor supervise this operation the first time to show you how much water to place in the pulley and how to place the drip pan.

Open the ammeter shorting switch and load the motor until it is drawing rated current. If everything appears as it should be, unload the machine. Now load up the machine using 8 to 10 increments of line current from the no load value to approximately 110% rated value, and take readings of line voltage (held constant), line current, field current (held constant), speed, and brake load. Precaution: Take the readings at the heavier loads as rapidly as possible, since considerable heat is generated. Lengthy runs at heavy loads will generate steam from the cooling water in the pulley. After the run is completed, close the ammeter shorting switches, unload the motor, and open the line switch in that order.

### Run II - Cumulative Compound Motor

Connect the motor as shown in Figures 2-E and 2-E(C). Remove the prony brake to make the following test. To be sure that the connection is cumulative, first start the motor with only the shunt field connected. Then start the motor with only the series field connected. If the direction of rotation is the same in both cases, the connection is cumulative. If the directions of rotation are opposite, reverse the series field and repeat the test. Precaution: A series motor tends to run away when unloaded; therefore, when starting the motor with only the series field in the circuit, care must be taken to prevent these excessive speeds. With the starter arm on the first contact, close the line switch and open it immediately. Since heavy current will flow when the switch is closed, shield the eyes from the line switch when opening and open it quickly.

After the above instructions have been carefully followed, install the prony brake and follow the procedure outlined in Run I.

### Run III-Differential Compound Motor

Connect the motor as shown in Figures 2-E and 2-E(B). This will require only a reversal of the series field in the connections for the previous run. Repeat the same tests made in the previous run except that the two fields should cause the motor to rotate in opposite directions when connected in the circuit alternately. Be absolutely sure that

the procedure outlined in the precaution of the previous run is scrupulously followed in making these tests.

Generally follow the procedure used in the first two runs with the following exceptions:

With the motor at rated voltage, adjust the shunt field to the highest value that can be held constant. Vary the load from 0 to the highest value of line current that can be obtained to give a stable reading. This occurs at about half load, and beyond this point the motor becomes too unstable to give accurate readings. When this unstable condition appears, do not attempt to take further readings, and do not increase the load further. An over-loaded differentially compounded motor will speed up until the two fields strengths are equal, then tries to stop and reverse direction. Besides causing possible damage to the prony brake equipment, this occurrence would cause scalding water to be thrown for some distance.

Report: For each run plot line current, speed, and efficiency as ordinates against horsepower output as abscissae. Also plot torque as ordinate against armature current. Discuss these curves and compare the characteristics of the different motors.

Give a diagram of the internal connections of the four point starting box and explain its operation. What is the disadvantage of using a three point box with a motor used for variable speed operation? Why was the warning

given not to let the starter arm slip off the first contact when starting the motor? If the shunt field should open while a shunt motor is running, what will happen with a four point box in the circuit? With a three point box? What will happen under this condition if no starting box is in the circuit?

Explain in detail how a D.C. motor adjusts its armature current to a change in load. Compare shunt with compound.

List all the precautions you can think of that should be taken in the operation of each type of motor.

#### Comments:

The greatest hazard to be encountered normally in the performance of this experiment is the improper use of the prony brake. This device should be operated with the utmost care, and it is not recommended for general use in loading motors. Since it is still in rather wide use, however, it is felt that its operation should be covered. For that reason, it is specified in this experiment.

The experiment includes a brief discussion of the proper operation of the prony brake and also several precautions. These precautions are necessarily brief and should be expanded by the instructor in the pre-laboratory discussion period.

To avoid interrupting the continuity of the written instructions with too many parenthetical precautions or

explanations, definite procedures are given in some instances without an accompanying reason. For example, in Run I the student is instructed to start the motor with all field resistance out; that is, with a strong field. He is also told to be sure that all his field connections are tight. It is not explained that one of the reasons for these instructions is that a weakened field can cause excessive speeds in an unloaded shunt motor. These explanations should be included in the pre-laboratory discussion.

The proper behavior when working in close proximity to moving machinery should be stressed.

Because of the danger accompanying the overloading of a differential compound motor, close supervision should be maintained to see that the written procedure is followed exactly.

## Experiment No. 3

Load Characteristics of a Series Motor

Object: To determine the load characteristics of a series motor using a dynamometer-generator for loading, and to learn the precautions to be observed in the operation of this type of motor.

Apparatus to be Tested: 7.5 Horsepower, 125 volt direct current motor.

Test Equipment: One D.C. ammeter, 0-100 amperes; one D.C. ammeter, 0-15 amperes; one D.C. voltmeter, 0-150 volts; one speed counter.

Procedure: (Read through carefully before starting.)

Connect the equipment to be tested as shown in Figure 3-E and have your instructor check your connections. Arrange the equipment to keep leads and connection points out of the working area to reduce the possibility of accidental contact with working voltages. If it is desired, a prony brake similar to that shown in Figure 2-E(D) can be used in place of the dynamometer-generator; however, it is not recommended. Two items of equipment unique to this experiment are the underload breaker, and the two point starting box with the underload release holding coil.<sup>10</sup>

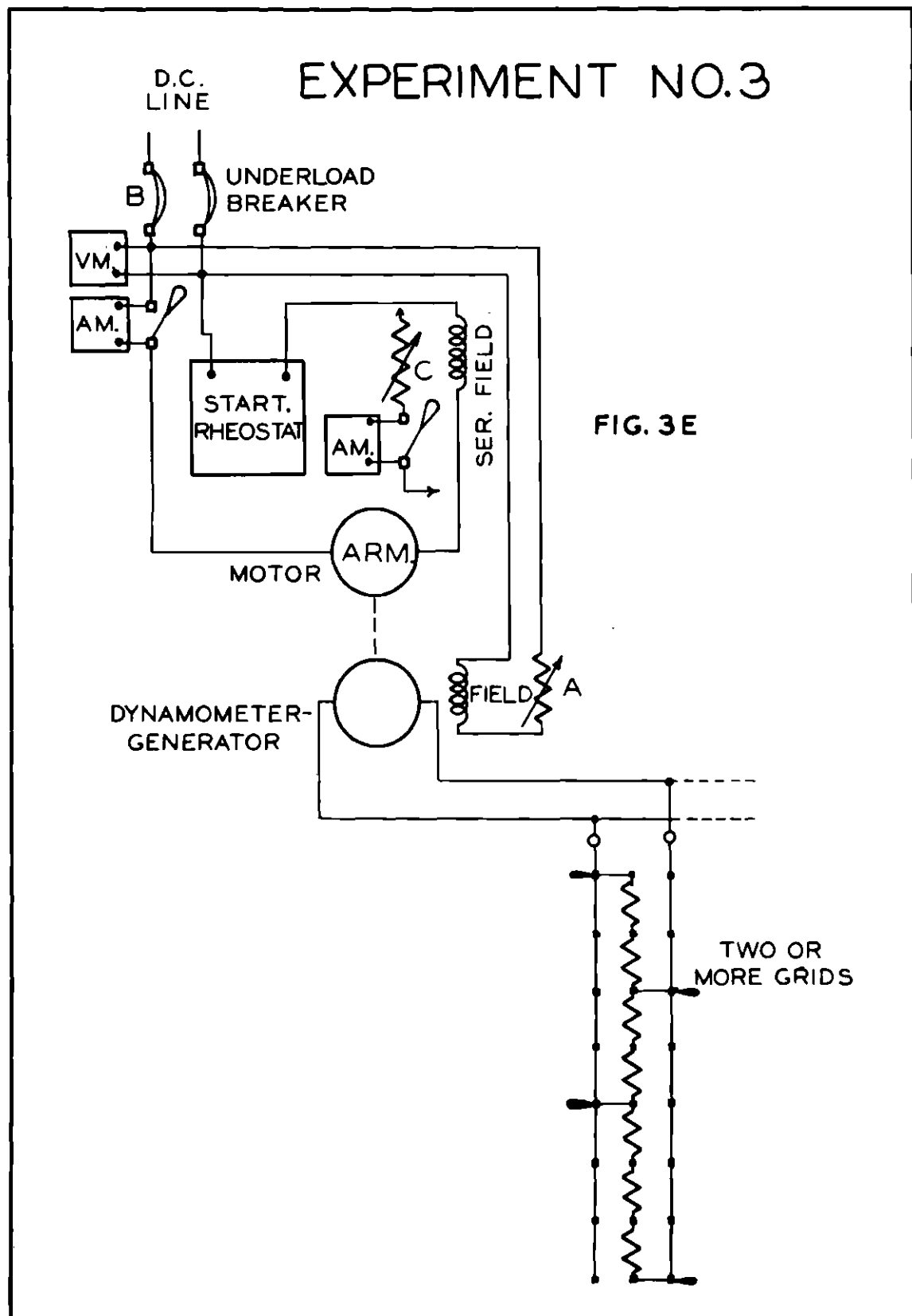
The primary hazard encountered in the operation of this type of motor is the danger of starting the motor without load, or of unloading the motor while it is running.



Under either of these conditions excessive speeds are quickly reached, and become sufficiently large to damage the machine and seriously injure the operator. As the speed increases, the current drawn by the motor decreases. It can be seen then, that if the circuit can be opened when the current is reduced below a predetermined safe value, the motor will be stopped before the dangerous speeds are encountered. This is the function of the under-load breaker.

The starting box consists of a low resistance rheostat which has a holding coil in series with it. The holding coil is also an underload device; that is, it releases the starter arm when the current drops below a safe value.

Check all connections to be sure they are tight, and close the ammeter shorting switch. Set the generator field rheostat to provide a strong field. Using the grids, place a load on the generator. Now, with the starting arm on the first contact, close circuit breaker B and slowly bring the starting arm up to running position. Check for proper operation of the torque weighing mechanism on the dynamometer-generator. Also check the line voltage to see that it is within three volts of rated value. Open meter shorting switches momentarily to check deflection. If everything appears to be operating properly, stop the motor by operating the breaker. Do not remove the load entirely at any time, whether the motor is running or not. One man



should be assigned to stand by the breaker at all times while the motor is running, ready to open the breaker in case of excessive speeds.

#### Run I-Load Test

Start the motor as before and adjust the generator load until the motor speed is 125% of the rated value. Vary the speed downward in about 8 increments until 125% rated load is reached. At each increment read line voltage, line current, speed, and the force exerted on the torque weighing mechanism. After completing the run, close the meter shorting switches, and remove as much grid load as possible without incurring excessive speeds. Now open the breaker.

#### Run II-The Use of a Diverter With The Series Motor

Connect the diverter C as shown in Figure E-3. With the diverter resistance out, start the motor. Adjust the diverter to take 15% of the line current. With the same minimum load used in Run I as the starting point, proceed as in Run I. At each increment, adjust the diverter current, if necessary, to 15% of the line current. After completing the run, close the meter shorting switches, remove part of the grid load as in Run I, and open the breaker.

Report: Plot graphs using armature current as abscissa, and efficiency, torque, and speed as ordinates. Compare the curves obtained:

For what kind of service do the characteristics of the

series motor make it well adapted?

Explain the effect of the following on the speed of a series motor:

- (a) Shunting the field.
- (b) Shunting the armature.
- (c) Increasing the line resistance.
- (d) Changing the applied voltage.

Can you suggest any ways to make this experiment safer?

Comments:

The series motor either is treated lightly or is omitted entirely in the majority of the laboratory manuals examined. In at least one case, this experiment was omitted because the faculty felt that non-electrical students did not have an electrical background sufficiently complete to justify their operation of such inherently hazardous machines.

It is believed that the theory of the series motor is important; and that the corresponding laboratory work can be so arranged and the laboratory equipment used can be selected to allow the safe performance of this experiment.

While the prony brake can be used for this experiment, it is a hazardous device, particularly when used in conjunction with a series motor; therefore, this experiment has been written for use with the dynamometer-generator type of loading. While dangerous speeds can be obtained with the

latter type if the generator is completely unloaded, the speeds reached will not be as high as those reached if the generator were not mechanically connected to the motor. In other words, the hazard is greatly reduced by having a generator permanently connected to the motor, but it is not entirely eliminated.

Careful consideration should be given not only to the laboratory procedure followed, but also to the inclusion of such safety devices as are applicable. With this thought in mind, the underload circuit breaker and the starting box with the underload opening device were utilized. Both devices should be carefully adjusted and reserved for this experiment only. Since it is more desirable for the circuit to be opened by the breaker, it is suggested that the breaker be adjusted to open at a slightly higher current than the holding coil on the starting box. Of course, the experiment could be run omitting either of these devices, but it is believed that the use of both is desirable.

If a greater degree of protection is desired, consideration might be given to the provision of a light permanent load on the motor that cannot be removed easily. Several possibilities come to mind immediately, such as the use of a modified magnetic brake permanently wired into the motor circuit. The principal disadvantage with this type of device seems to be the possibility of leaving the student with the impression that unloaded series motors

aren't particularly dangerous, or that most series motors have a built-in load as a protective device. Therefore, if such a device is used, care should be taken to avoid these impressions.

The pre-laboratory discussion of this experiment should include the safety devices mentioned above and how they operate. The procedure should be covered until the reason for each move and its position in the sequence is understood from a safety standpoint. As suggested in the written procedure, one man should be assigned to stand by the circuit breaker at all times in case of trouble. He should be cautioned to watch the resistance load on the generator continuously to see that it is never entirely removed.

## Experiment No. 4

Characteristics of Direct Current Shunt and  
Compound Generators

Object: To study the characteristics of self-excited and separately excited shunt generators, and self-excited cumulative and differential compound generators.

Apparatus to be Tested: Motor-generator set.

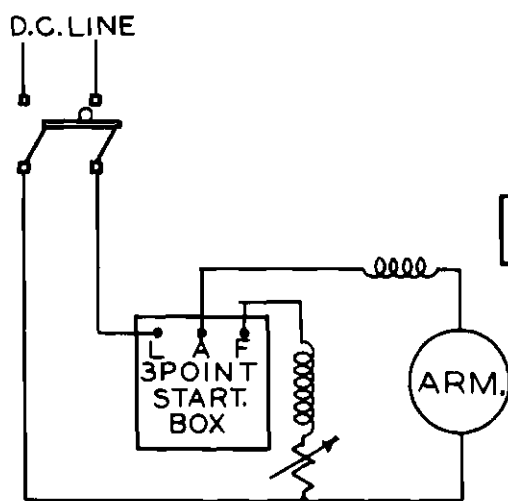
Test Equipment: One D.C. ammeter, 0-5 amperes; one D.C. ammeter, 0-50 amperes; one D.C. voltmeter, 0-150 volts; speed counter; and strobotac

Procedure: (Read through entirely before starting.)

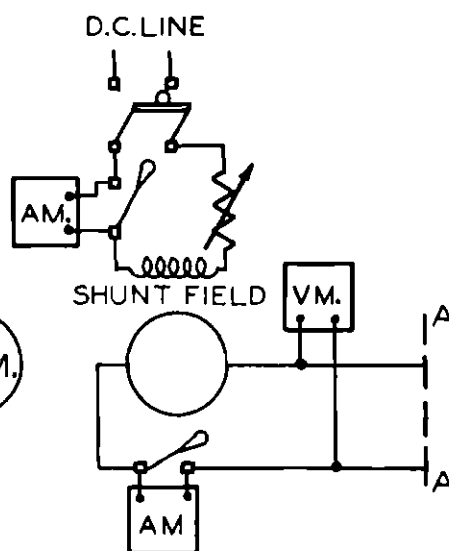
A direct current compound motor is used to drive the generator to be tested, using a three point starting box. Read that part of Experiment No. 1 which covers the proper use of grids, and the opening and closing of switches under load.

A strobotac is used to watch for speed variations during the run. This device uses a flashing neon light which is focused on the motor-generator shaft. When this light blinks once for each revolution of the shaft, it flashes on the same side of the shaft each time and the rotating shaft appears to stand still. Any variation of speed will show up as a slow rotation of the shaft in the direction of the change. Take care not to mistake the shaft under the light of the strobotac as being at rest during the runs.

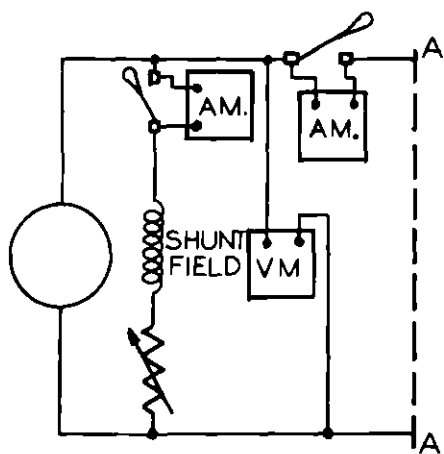
## EXPERIMENT NO.4



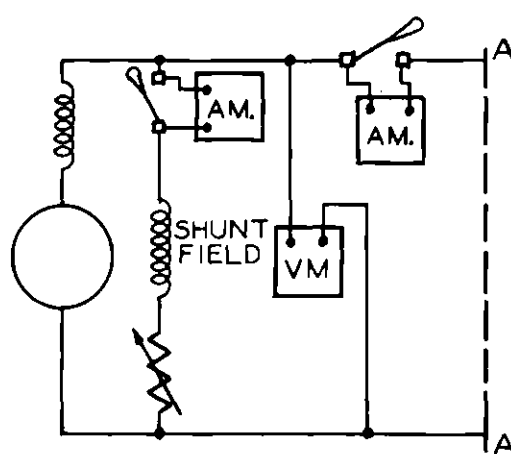
DRIVING MOTOR  
FIG. 4 E



SEPARATELY EXCITED  
SHUNT GENERATOR  
FIG. 4E (A)



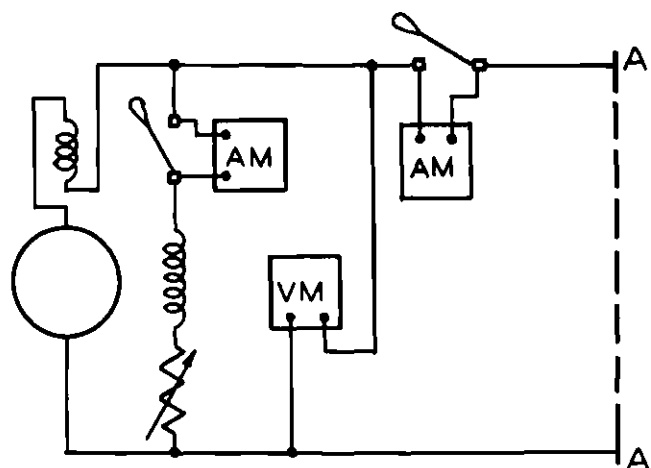
SELF-EXCITED  
SHUNT GENERATOR  
FIG. 4 E (B)



SELF EXCITED CUMULATIVE  
COMPOUND GENERATOR  
FIG. 4 E (C)



## EXPERIMENT NO. 4



SELF EXCITED DIFFERENTIAL  
COMPOUND GENERATOR  
FIG. 4E(F)

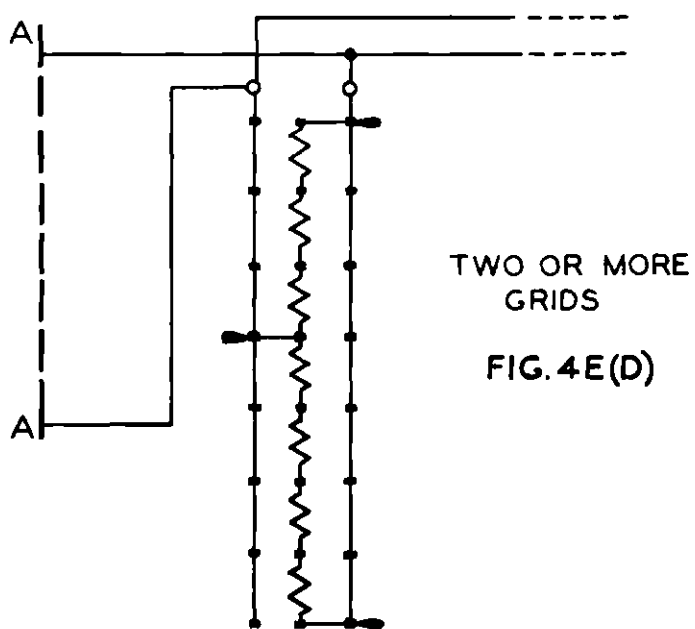


FIG. 4E(D)

This has happened often in industry in a moment of thoughtlessness.

### Run I-Separately Excited Shunt Generator

Connect the equipment as shown in Figures 4-E, 4-E(a), and 4-E(D), and have your connections checked by the instructor. Arrange the test equipment to keep connections and leads away from the working area. Not to do so enhances the chance of tripping or shock. Tighten all connections, especially those in the shunt field circuit of the driving motor. If the shunt field becomes accidentally disconnected, the driving motor would operate as a series motor, and would introduce the hazards associated with it.

When these precautions have been taken, place the starting arm on the first contact and close the motor line switch. If the direction of rotation is correct, move the starting arm slowly to the running position. If not, open the line switch, reverse the shunt field connections, and start the motor. Close the field switch, place a small load on the generator, and open the ammeter shorting switch momentarily to check deflection. If the direction of deflection is incorrect, remove the grid load and stop the motor before reversing the meter leads. Then start the motor as before.

Using the motor field rheostat, adjust the speed of the generator to its rated value. Use the strobotac to check the speed during the run. Close the field switch, and adjust

the generator field rheostat to bring the generator voltage up to rated value.

Keeping the speed and generator field current at rated value, vary the generator load from 0 to 125% of rated value in 8 increments. At each increment read speed, field current, load current, and terminal voltage. At the completion of the run, short the ammeters, remove the load, and open the line switch - in that order

#### Run II-Self Excited Shunt Generator

Change the connections to agree with Figures 4-E, 4-E(B), and 4-E(D). Start the motor and adjust the speed as in Run I. If the generator does not build up, vary the field resistance. If the generator voltage goes up as the resistance is increased, the generator field is connected opposing the residual magnetism of the field pieces. In this case reverse the field leads, stopping the motor first.

Leaving the field rheostat at the no load voltage setting and holding the speed constant, load the generator and take readings as in Run I. At the completion of the run, remove the load, short the ammeters, and open the line switch, in that order.

#### Run III-Self Excited Cumulative Compound Generator

Change the equipment to agree with Figures 4-E, 4-E(C), and 4-E(D). Start the motor as in Run I and determine whether the connection is cumulative or differential. This is done by loading the generator, holding the speed constant, and reading the voltage. If the voltage drops

rapidly with increasing load, the connection is differential. If the voltage is nearly constant with increasing load, the connection is cumulative. If the connection is differential, proceed with Run IV.

For the cumulative connection, take the same readings as in the previous runs. At the completion of the run, remove the load, short the ammeters, and open the line switch, in that order.

#### Run IV-Self Excited Differential Compound Generator

Connect the equipment as shown in Figures 4-E, 4-E(F), and 4-E(D). this consists merely of reversing the series field from the previous run. Start the motor, and adjust the speed and voltage as in the previous runs. Use increments of voltage in this run from no load until the voltage has dropped about 35% of the no load value. Take the same readings as before. After the run is completed, short the ammeters, unload the generator, and open the line switch, in that order.

Report: Using the current as abscissa, plot the voltage characteristics of all four runs on the same sheet of cross section paper.

Compare the characteristics of the various generators studied in this experiment.

What precautions should be taken in the operation of D. C. generators? Name all you can think of.

### Comments:

There are no outstanding safety considerations in this experiment as there were in the last two; however, there are several hazards recurring here that were present and were described previously.

The problem of working in close proximity to moving machinery is present. As was pointed out briefly in the experiment, the fact that the strobotac makes the connecting shaft between the motor and generator appear stationary is hazardous. A thinking person would realize that the shaft was rotating; yet many experienced operators in industry have leaned absentmindedly on moving shafts made to appear stationary by a stroboscopic effect. For this reason consideration should be given to the provision of a guard to enclose the shaft completely. A transparent plastic window can be provided to permit use of the stroboscope.

The pre-laboratory discussion should include a review of the rules set forth in the comments following Experiment No. 1, because many of the conditions covered by these rules exist in this experiment.

## Experiment No. 5

Series Resonance

Object: To study the behavior of a series alternating current circuit containing a resistance, an inductance, and a capacitance; and to learn some of the precautions to be observed when working with these units.

Apparatus to be Tested: One adjustable inductance, one adjustable capacitance, and one adjustable resistance (grid).

Test Equipment: One voltage regulator; one A. C. ammeter, 0-10 amperes; one wattmeter; one current transformer; one A. C. voltmeter, 0-150 volts; one A. C. voltmeter, 0-50-150 volts.

Procedure: (Read through entirely before starting.)

This is the first alternating current experiment where the properties of inductance or capacitance are involved, and several hazards should be mentioned.

As you know, comparatively low voltages can be fatal under favorable conditions. Did you know, however, that an A. C. voltage is much more dangerous than a D. C. voltage of the same value? Or that the voltage drop across an inductor or capacitor in a series circuit containing both can be considerably higher than the applied voltage? These facts make it apparent that additional care should be exercised in order to avoid contact with alternating current circuits.

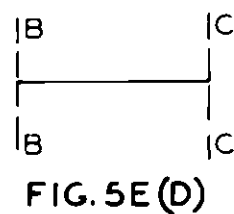
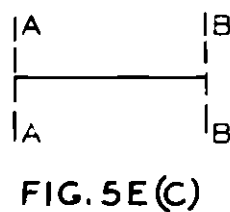
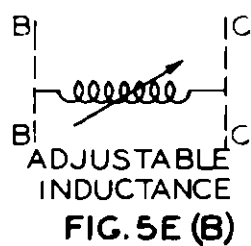
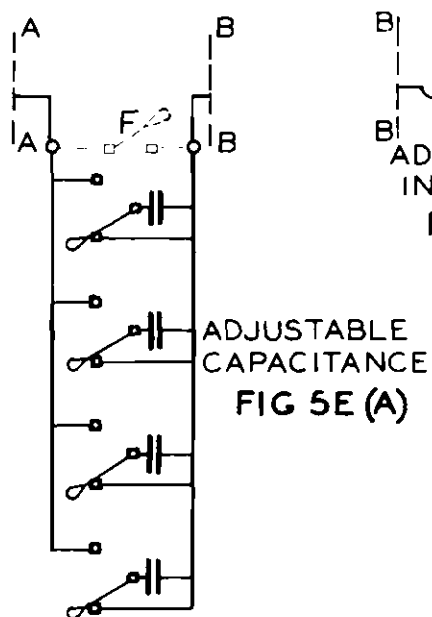
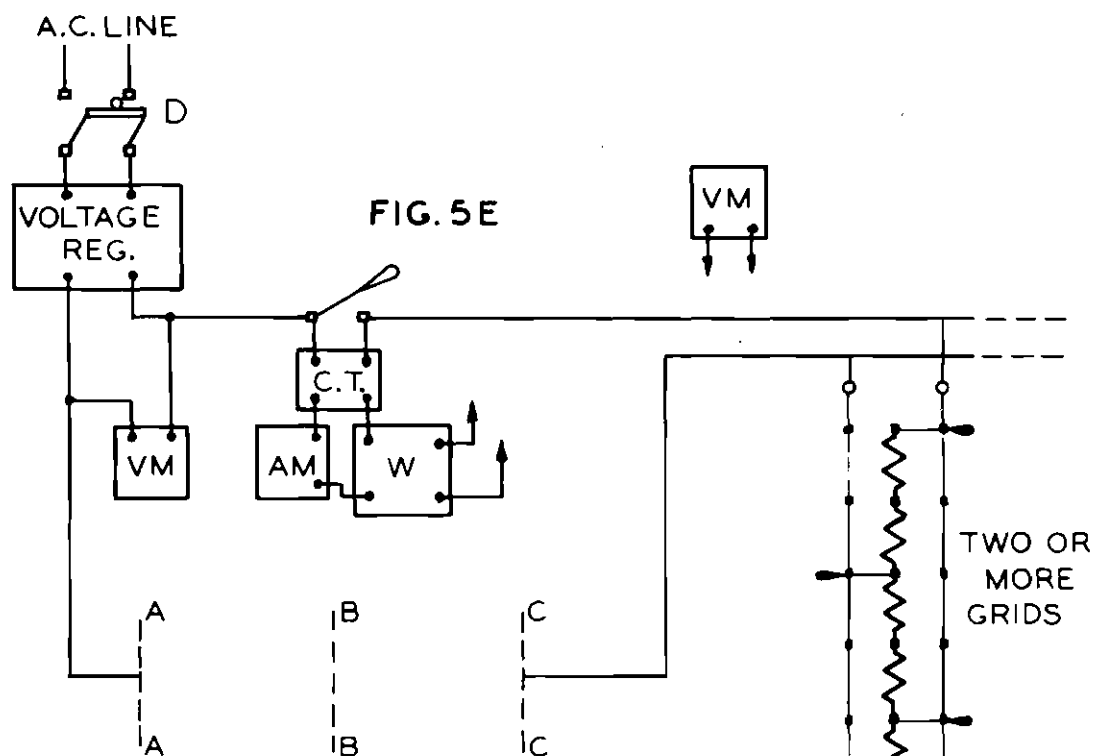
The adjustable capacitor has a three way toggle switch on each section. One position of the switch puts the section in the circuit; the other position shorts the section. Since there is no neutral position for the switch, the capacitor sections that are switched out of the circuit cannot be left in a charged condition. Upon completion of a run, all switches on the capacitor unit should be thrown to the "out" position to discharge all charged sections. Cases are on record where men have been fatally shocked by charged condensers that have been disconnected from electrical circuits for several days.

Connection to the capacitor unit is made by plugging the connecting leads into jacks on the unit. Main shorting switch F is a part of the jacks and is permanently wired so that when the connecting lines are removed, the unit is automatically shorted at the jacks. This means that the main shorting switch shown in the diagram is not visible and is not to be operated by the student. It is included in the diagram for the student's information.

Care should be exercised not to place any meters near the inductance unit, because the strong field from this unit can induce currents in the meter coil sufficient to burn it out. This field can also damage your watch if it is held near.

Always reduce the inductance in a circuit to the lowest possible value before opening the line switch, because a highly inductive circuit can cause severe arcing when opened.

# EXPERIMENT NO.5





## Run I

Resistance, Capacitance, & Inductance in Series

Connect the equipment as shown in Figures 5-E, 5-E(A), and 5-E(B), and have your connections checked by the instructor. Arrange the test equipment for clear working space free of leads and connection points. It is also important that all connections be tight. Be especially careful to locate capacitor leads so that accidental contact with them is difficult, and exercise care during the course of the experiment to see that you do not contact them.

With all capacitor sections shorted and the ammeter shorting switches closed, close line switch D and adjust the voltage regulator to 90 volts. Keep it at this value throughout the experiment. Set the grid to give 11 ohms resistance and adjust the capacitor to place 80 microfarads in the circuit. Adjust the inductance so that the voltage drop across both reactances ( $V_L \neq C$ ) is a minimum. (Care should be taken in holding the voltmeter leads on the contacts for this adjustment and all subsequent voltmeter reading that the hands contact only the insulation on the voltmeter leads. Another person should read the meter so that the man holding the leads can give that job his entire attention.) The inductance will be left at this value throughout the experiment.

Vary the capacitance from 20 to 160 microfarads in 20 microfarad increments and take the following readings

at each increment:

The voltage drop across the capacitor ( $V_C$ ), the inductor ( $V_L$ ), the resistor ( $V_R$ ), the entire circuit ( $V_O$ ); the power used by the capacitor ( $P_C$ ), the inductor ( $P_L$ ), the resistor ( $P_R$ ), and the entire circuit ( $P_O$ ); and the line current ( $I_O$ ).

Upon completion of the run, close the meter shorting switches, short out all the capacitance sections, remove the load from the grid, and open the line switch, in the order given.

#### Run II-Resistance and Capacitance in Series

Connect the equipment in accordance with Figures 5-E, 5-E(A), and 5-E(D). This involves only removing the inductor from the circuit. Proceed as in Run I in setting the line voltage, grid resistance, and capacitance (80 mfd). At this one setting only, take the same readings as in Run I except those involving the inductor. Upon completion of the run, disconnect in the same order given in Run I.

#### Run III-Resistance and Inductance in Series

Connect the equipment in accordance with Figure 5-E, 5-E(B), and 5-E(C). This involves removing the capacitor and returning the inductor to the circuit. With the same line voltage, grid resistance, and inductance setting as in Run I, take the same readings as were taken in Run I except those which involve the capacitor. Upon completion

of the run, disconnect in the order given in Run I.

Report: Using the capacity of the condenser in microfarads as abscissa, plot on one sheet of cross section paper  $I_C$ ,  $V_R$ ,  $V_L$ ,  $V_C$ ,  $V_L / C$ ,  $Z_0$ , and power factor.

Draw the vector diagram of all voltages and current for Run II, Run III, and the increment of Run I that was at resonance. Be sure to label all vectors with correct values of voltage or current, and label all angles.

It was stated that voltage drops across one unit in an alternating current circuit can be substantially larger than the voltage applied to the entire circuit. Did this occur in this experiment? If so, across what units?

Can you suggest precautions that might be taken to make this experiment safer?

Comments:

The capacitor unit as described in the experiment was designed to be as safe as possible. Consideration was given to the provision of another main shorting switch, one that could be operated by the student. It was decided, however, that the shorting arrangement incorporated in the jacks was sufficient.

This first alternating current experiment should be preceded by a complete discussion of the hazards unique to the various A. C. apparatus to be used in the laboratory. Most of these hazards were covered briefly in the written experiment.

## Experiment No. 6

A Study of the Three Phase Generator

Object: To study the operation of the three phase alternating current generator, and the measurement of power by the two wattmeter method.

Apparatus to be Tested: 3 phase, 60 cycle, 5 KVA, 110/220 volt, alternating current generator driven by a direct current shunt motor.

Test Equipment: 3 A. C. ammeters, 0-30 amperes; one D. C. ammeter, 0-15 amperes; 3 current transformers; 2 wattmeters; one A. C. voltmeter, 0-150 volts; one strobotac.

Procedure: (Read through entirely before starting)

This is the second alternating current experiment, and the first involving polyphase currents and circuits. Review the properties of polyphase currents in your text book. From this review and from your experience, if any, make a list of precautions to be observed in working with polyphase circuits and machines. This should be done some time prior to the running of the experiment, since your list will be checked by the instructor in the discussion period prior to the laboratory period in which the experiment is to be run. At that time lists will be compared and a composite list made up. This composite list should be included as a part of your written report.

# EXPERIMENT NO.6

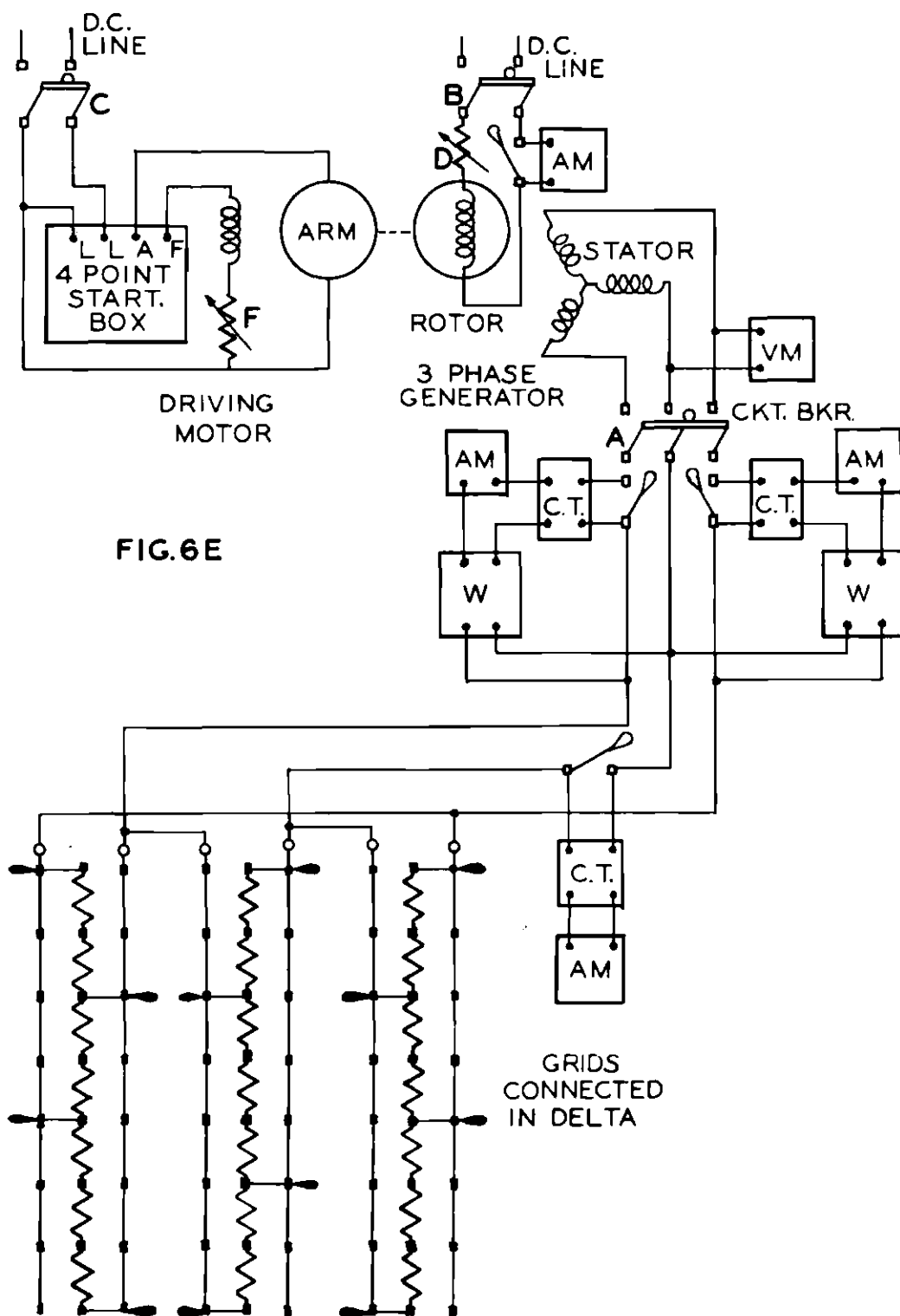


FIG.6E

### Run I-Excitation Data

Connect the equipment as shown in Figure 6-E with the generator connected for 220 volt operation, and have your instructor check the connections. Using the formula  $n = \frac{120f}{p}$ , calculate the speed at which the generator must turn to generate 60 cycle current, and set the strobotac to this calculated figure. (Do not fail to arrange the test equipment to keep the working area clear of leads and connections.)

With circuit breaker A and D. C. line switch B open, and with field rheostat F set to provide a strong field, close line switch C. Start the D. C. driving motor and bring it up to the synchronous speed of the alternator. Use the strobotac to adjust the speed to the predetermined value, and hold it there throughout the experiment.

With the ammeter shorting switch closed, close the line switch to the generator excitation circuit B. Open the shorting switch momentarily to check the deflection of the meter. If the deflection is correct, reopen the shorting switch, adjust the field current to a low value, and read the voltmeter. Increase the field current to give increments of 20 volts on the output voltmeter until a maximum is reached, and read the field current and output voltage at every increment. After completing the run, proceed with Run II.

### Run II-Load Test

With the ammeter shorting switches closed and all grid switches open, close circuit breaker A. Open shorting switches, and adjust the grids and field rheostats as necessary until the generator is delivering rated load at 220 volts and is turning at synchronous speed. The load should be balanced; that is, all three lines from the generator stator should be carrying equal currents. Maintaining the speed and field current constant, decrease the load in 8 increments to no load. At each increment record the readings of all meters.

Report: Plot an excitation curve using the data secured in Run I, and a load current - voltage curve from Run II.

Calculate the per cent voltage regulation for the generator.

Explain why the two wattmeter method of measuring three phase power actually measures the total power.

Comments:

This experiment has no hazards that are unusual or unique to equipment involved in the experiment. The hazards to be guarded against are those brought out in past experiments, such as working in the vicinity of rotating machinery, the stroboscopic effect of the strobotac on the rotating shaft, and the improper operation of switches.

The voltage in this experiment is slightly higher than that used in previous experiments; however, it is of

greater concern that both alternating and direct currents are being used simultaneously. There is a real possibility of getting D. C. into A. C. circuits and vice versa. While this does not present an accident hazard in itself, the confusion that would result from D. C. unexpectedly arcing on an A. C. switch or the burning out of testing equipment might easily precipitate an accident. The answer in this case seems to be close supervision by the instructor on the wiring of the circuits.

The written procedure has been prepared in the best sequence to avoid unnecessary exposure to heavy currents or high voltages, as have been the procedures in the previous experiments. It is suggested that emphasis be given in the pre-laboratory discussion to close following of the written procedure sequence of operations.



## Experiment No. 7

### A Study of The Transformer

Object: To determine the efficiency and regulation of a single phase transformer, and effect of the power factor of the load on regulation.

Apparatus to be Tested: 1.5 KVA, 230-115 volt transformer.

Test Equipment: One induction type voltage regulator; two current transformers; two A. C. ammeters, 0-10 amperes; one A. C. voltmeter, 0-150 volts; one A. C. voltmeter, 0-300 volts.

Procedure: (Read through entirely before starting.)

Transformers are devices whereby alternating electrical energy can be received at one voltage level and delivered at another voltage level. These two voltages will have the same frequency, and will be in the same ratio as the number of turns in the primary winding to the number of turns in the secondary winding. They are useful units of electrical equipment, but they can cause equipment damage or injury to personnel if not used properly.

Never apply direct currents to a power transformer, except perhaps small test voltages such as would be applied in the use of an ohmmeter. (Power transformers were specified because D. C. bias often flows through transformer windings in radio circuits. These are usually very small transformers by comparison to those used on power lines.) When it becomes necessary to use direct currents, carefully



guard against contact with the coil not being energized. Although the test circuit is complete, no current will flow in the unenergized coil; however, at the moment of breaking this circuit, the collapsing magnetic field will induce a sizeable amount of electrical energy in this coil. Often less than ten volts can cause an induced voltage much larger, large enough to cause a severe shock.

#### Run I-Load Test

Connect the equipment as shown in Figure 7-E, and arrange the test equipment to keep leads and connections away from the working area. Have your instructor check your connections. Be sure that the primary coils are in series and the secondary coils are in parallel. If this were reversed; that is, if the primary were connected in parallel and the secondary in series, the secondary output would be 460 volts. This voltage would damage the instruments in the secondary circuit; and it would be hazardous to personal safety, particularly since voltages of this size would not be expected.

With the grid switches open and the meter shorting switches closed, close the line switch. Adjust regulator to 230 volts and read all the meters for zero load. Keep the primary voltage constant and vary the secondary current from 0 to 125% rated value in ten increments. At each increment record the reading of all meters. When the run is completed, unload the grids, close the meter shorting switches, and open the line switch, in that order.

Run II-Load Power Factor, Lagging-  
Its Effect on Regulation

Connect the equipment as shown in Figures 7-E and 7-E(A). This consists merely of adding an inductance in parallel with the grids. Care should be taken not to locate meters too close to the inductance, since the strong field created can burn out the meters by inducing currents in them. In fact, no equipment having coils should be located within the influence of this field, since the current induced could easily cause a severe shock to an unsuspecting person.

Set the inductance to its lowest value, and with the meter shorting switches closed and the grid switches open, close the line switch. Adjust the load to 80% power factor lagging, for full load as follows:

1. Calculate the reactive component of the current for full load at 80% power factor and adjust the inductance to draw this amount of current with all the grid switches open.

2. Add load using the grids until the current is at the desired total value. This should give the desired power factor.

3. Check the power factor, using the voltmeter, ammeter, and wattmeter readings.

When the power factor has been adjusted satisfactorily, record the readings of all the meters. Now close the

meter shorting switches, reduce the inductance to a minimum, and open the line switch, in that order. It is important that the inductance be reduced before opening the switch because a strongly inductive circuit can cause severe arcing when opened.

Run III-Load Power Factor, Leading-  
Its Effect on Regulation

Connect the equipment as shown in Figures 7-E and 7-E(B). This requires the replacement of the inductance with a capacitance similar to the one used in Experiment No. 5. The capacitance shorting switch is shown for information only, because it is a part of the terminal jacks and can be closed only by disconnecting the unit from the circuit. The hazards associated with capacitances, which were covered in previous experiments should be reviewed before proceeding further.

With the grid switches open, the ammeter shorting switches closed, and all the capacitor switches in the "out" position, close the line switch. Using the same procedure outlined in the previous run for establishing the desired power factor, adjust the circuit to an 80% leading power factor at full load. Read all meters and record. Now close the meter shorting switches, remove the grid load, throw all capacitor switches to the "out" position, and open the line switch, in that order.

Report: On one sheet of cross section paper plot secondary voltage and efficiency as ordinates, using KW output as abscissa.

Compare the regulation and efficiency at full load for unity, lagging, and leading power factors.

Why is the transformer generally more efficient than other electrical apparatus of similar rating? Compare with a generator of equal rating.

Is any other electrical equipment more efficient than a transformer? If so, what?

Comments:

The principal hazards to be expected in the performance of this experiment have been covered briefly in the written procedure. These may be expanded by the instructor in the pre-laboratory discussion.

## Experiment No. 8

A Study of The Squirrel Cage Induction Motor

Object: To determine the characteristics of a polyphase induction motor.

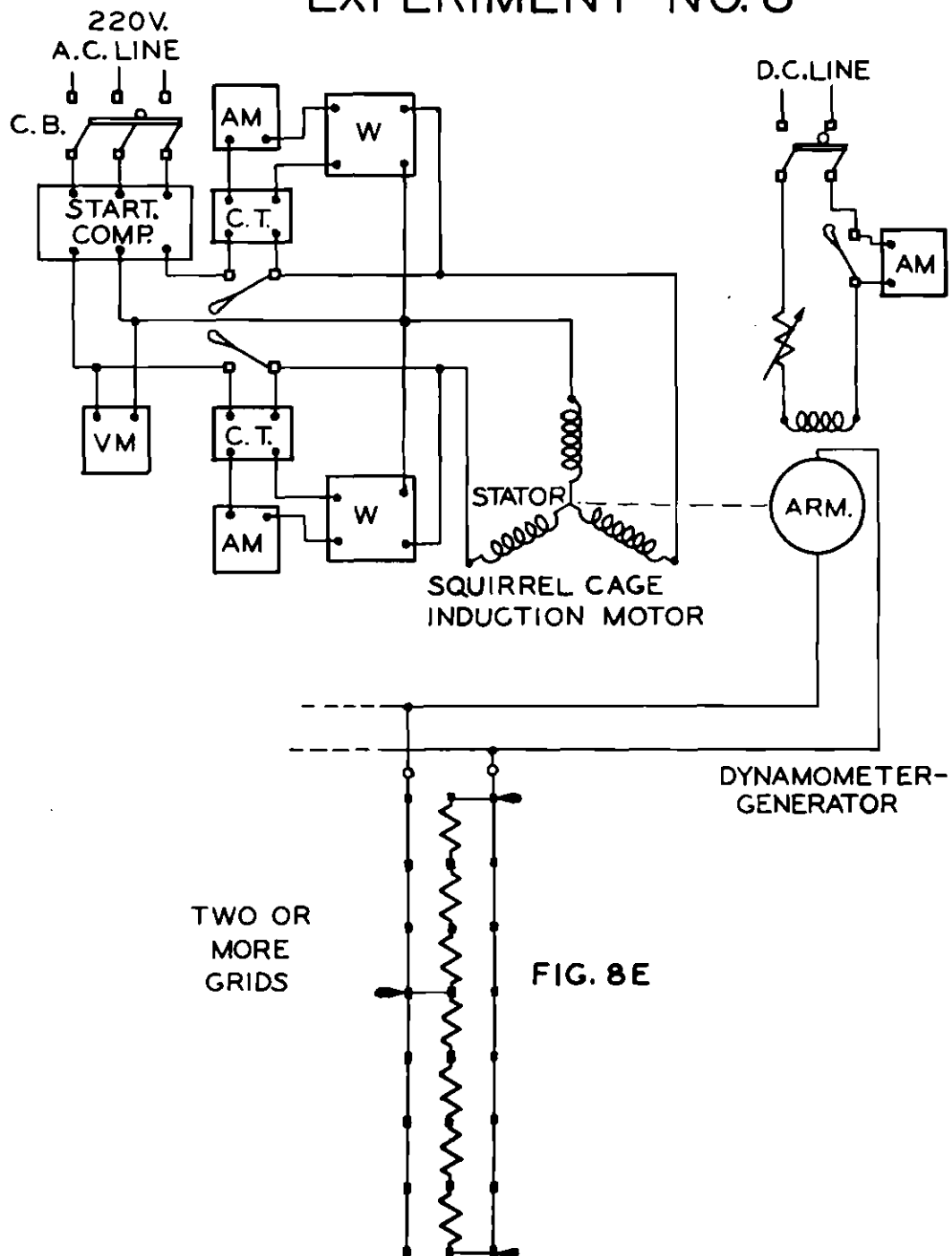
Apparatus to be Tested: 5 H. P., three phase, 18.2 amperes line, 220 volt, 60 cycle squirrel cage induction motor.

Test Equipment: One A. C. voltmeter, 0-300 volts; two current transformers; two A. C. ammeters, 0-10 amperes; one D. C. ammeter, 0-5 amperes; two wattmeters; one speed counter; and one strobotac.

Procedure: (Read through entirely before starting.)

The compensator performs the same function here that the starting box does for the direct current motor. When the arm is in the starting position, a reduced voltage is applied to the motor by means of tapped auto-transformers. The arm should be held in this position until the motor is no longer gaining speed; then the arm should be removed to the running position in a quick, forceful manner. In this position full line voltage is applied to the motor. Failing to allow the motor to gain sufficient speed before moving the compensator arm to the running position will result in the motor drawing a starting current large enough to be damaging to the equipment, which would endanger personnel in turn. Guard against the possibility of contacting live terminals while concentrating on the operation of starting lever.

## EXPERIMENT NO. 8





### Run I-Load Test

Connect the equipment as shown in Figure 8-E, and have the instructor check your connections. Arrange the test equipment to keep leads and connections out of the working area. Be sure to keep connections and meters away from the compensator, so that they will not be struck while operating the starting lever.

Disconnect the dynamometer-generator from the motor. With the meter shorting switches closed, close the A. C. line breaker and start the motor as previously instructed. Record the readings of all meters and the speed. Close the meter shorting switches, and then open the line breaker. Do not attempt to stop the motor with the compensator as this may damage the internal contacts of the compensator by arcing.

Connect the dynamometer-generator to the motor. With the grid and the D. C. line switches open and the meter shorting switches closed, close the A. C. line breaker and start the motor as before. The D. C. switches are left open to unload the motor as much as possible during starting. Load on the motor while starting causes additional current to be drawn with correspondingly additional hazard to personnel and equipment.

If it is not given, calculate the full load torque of the motor. Close the D. C. line switch and open the D. C. ammeter shorting switch momentarily to see if the meter deflection is correct. If not, open the D. C. switch

before reversing the meter leads. If the deflection is up scale, open the shorting switch and adjust the shunt field current to rated value. Load the motor using increments of 20, 40, 60, 80, 100, and 120% of full load torque. At each load increment, record the readings of all meters, the dynamometer, and the speed. Slip can be measured by means of the strobotac. The direct current dynamometer-generator is loaded by means of the grids, and fine adjustments can be made by using the shunt field rheostat.

Report: Using one sheet of cross section paper and using horsepower output as abscissae, plot line current, power factor, per cent slip, efficiency, and speed as ordinates. Discuss the curves obtained, including the answers to the following in your discussion:

(a) Why does the power factor increase with increasing load?

(b) Why does the speed decrease with increasing load?

(c) Give a comparison of the induction motor and the direct current shunt motor.

(d) How is the direction of rotation of a three phase induction motor reversed?

(e) What is the purpose of the variable resistance sometimes used in the rotor circuit of a wound rotor induction motor?

Comments:

Several of the laboratory manuals examined specified the use of a prony brake for this experiment; however, because of the increased hazard accompanying the use of this device in comparison with the use of the dynamometer-generator, this experiment was written to utilize the latter. By so doing, the safety considerations of the experiment were reduced almost entirely to the routine items common to all electrical laboratory work, such as the hazards associated with working in the vicinity of rotating machinery, and with the use of switches. The few special considerations necessary were covered in the experiment itself, and might be expanded in the pre-laboratory discussion.

## Experiment No. 9

Characteristics of a Synchronous Motor

Object: To determine the operating characteristics of a synchronous motor.

Apparatus to be Tested: 5 KVA, 220 volt, three phase, 60 cycle, 1200 R. P. M. synchronous motor.

Test Equipment: One A. C. voltmeter, 0-300 volts, two D. C. voltmeters, 0-150 volts; two current transformers; two A. C. ammeters, 0-10 amperes; one D. C. ammeter, 0-50 amperes; one D. C. Ammeter, 0-10 amperes; two wattmeters; one strobotac.

Procedure: (Read through entirely before starting.)

The synchronous motor will run only at synchronous speed; therefore, some arrangement must be made for starting the machine. Usually damper windings are provided to give a small starting torque, and the machine is started as an induction motor. Since this starting torque is small, the motor should be loaded as lightly as possible while starting, and the motor field must be closed through a suitable resistance. This is necessary to hold down the high voltage which would be generated in the D. C. winding, a voltage high enough to break down the insulation of the winding. Besides the damage to the machine, voltages of this size are dangerous to personnel and could cause a serious injury.

Sometimes, when a direct current generator is con-

# EXPERIMENT NO. 9

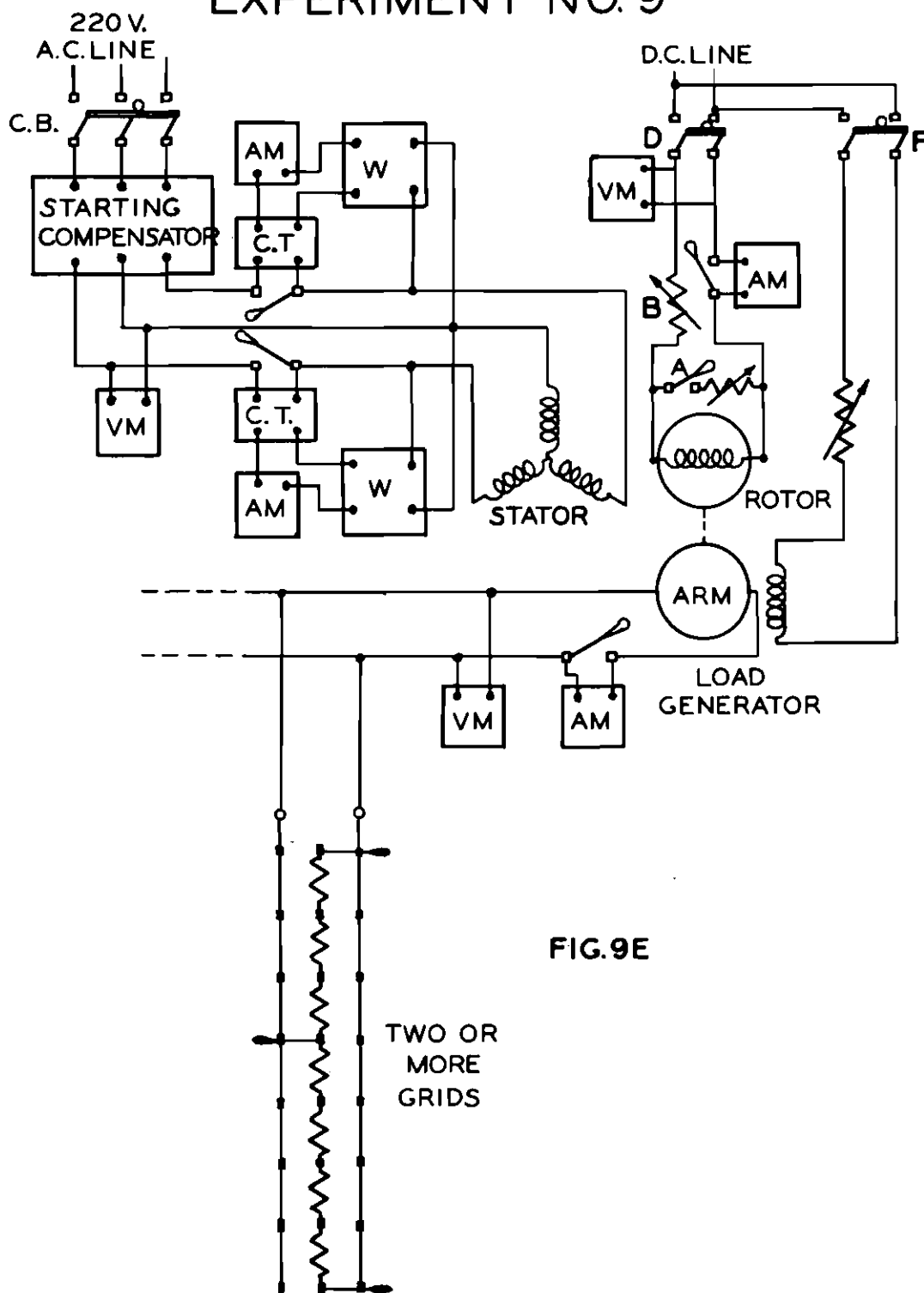


FIG. 9E

nected directly to the synchronous motor, the generator can be driven as a motor to bring the synchronous motor up to synchronous speed. In this case the phase sequence and the voltages of the A. C. line and of the synchronous machine must be matched before the A. C. line switch is closed.

### Run I-Load Test

A compensator will be used for starting in this run and a A. C. generator will be used to load the motor.

Connect the equipment as shown in Figure 9-E and have the instructor check your connections. Arrange the equipment to keep leads and connections out of the working area. To start the motor, proceed as follows: Check to see that the D. C. line switches and all grid switches are open, and close all meter shorting switches. Also be sure to close switch A, which puts the required starting resistance in the D. C. field circuit of the motor.

When the precautions have been complied with, the A. C. line switch should be closed and the compensator handle pulled to the "start" position. Note the direction of rotation. If it is wrong, the handle should be released, the line switch opened, and two of the line leads to the motor should be reversed. When the direction of rotation is correct, the handle of the compensator should be held in the "start" position until the motor reaches a maximum speed. Then the handle should be pulled quickly to the

"run" position where it will lock and should remain until the line switch is opened.

Now close the D. C. line switch D and open switch A. Close switch F and adjust the field rheostat B until the field current is slightly larger than that which produces the minimum alternating current. At this point place a very light load on the generator and check all the D. C. meters to be sure that they are reading up scale. If not, remove the load and open the line switches before reversing the leads on the meters. The reason for this should be clear, because you should never work on a live circuit unless it is absolutely necessary.

Adjust the excitation to give unity power factor at rated load. To do this, first load the motor until it is drawing approximately rated current, then vary the motor field excitation until the A. C. line ammeters are reading a minimum. Repeat this until the minimum falls at rated current for the motor. This is unity power factor, and the excitation should remain at this value throughout this run. Note the generator load current at rated motor load, because it is easier to use increments of this current in making the run.

Using increments of 0, 20, 40, 60, 80, 100 and 120% rated load, record the readings of all meters at each increment. Upon completion of this run, proceed immediately with Run II.

## EXPERIMENT NO. 9

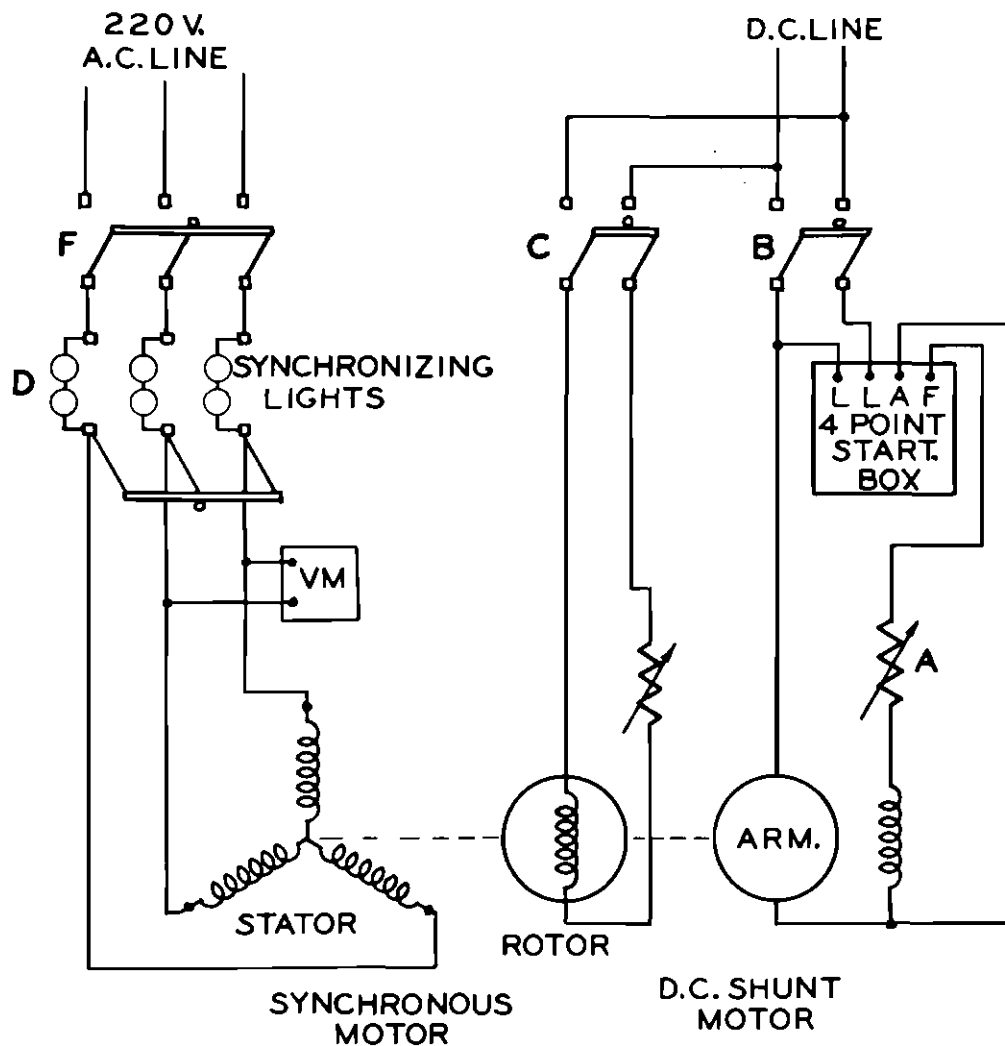


FIG. 9E(A)



### Run II-Excitation and Power Factor

Adjust to unity power factor at rated load as in the previous run. Now reduce the excitation until the line current is 120% of the rated value. Holding the load constant, increase the excitation in about six steps until the line current is again 120% of rated value. At each step record the readings of all meters. When the run is completed, unload the generator and close all meter shorting switches. Now open the A. C. line switch first, before opening the D. C. circuits.

### Run III-Using a Direct Current Motor for Starting

Connect the equipment as shown in Figure 9-E(A). Only one voltmeter is used in this run, since the purpose of the run is to familiarize the student with this type of starting, and no readings will be recorded.

With all switches open, set rheostat A to provide a strong field, and with the handle of the starting box on the first contact, close D. C. line switch B. If the direction of rotation is incorrect, stop the motor by opening the line switch, reverse the shunt field leads, and start the motor again. Slowly bring the starting arm around to "running" position. Set the strobotac to the synchronous speed of the A. C. machine and, by adjustment of the shunt field, bring the speed of the machine to this value. Make sure that you have reached the proper speed, because a stroboscopic effect can be attained at fractions of this speed.

Close D. C. switch C and adjust the synchronous motor field until the voltmeter reads 220 volts. Close line switch F and look at the synchronizing lights. If all three are blinking together, the phase sequence of the motor and the A. C. line are the same. If the lights are blinking in rotation, the phase sequence must be changed. To do this, stop the D. C. motor, open switches C and F, and reverse two of the line leads of the synchronous motor. Do not attempt to change these leads with the machines rotating, because the synchronous motor is acting as a generator, and is capable of causing a severe shock.

With the phase sequence correct, and the machines running at the speed of the strobotac setting, adjust the field rheostat A until the synchronizing lamps are blinking very slowly. Now close A. C. switch D quickly, when the lamps are dark. If this switch should be closed when the lamps are bright, the A. C. line and motor voltages are 180 degrees out of phase and a combined voltage of approximately 440 volts will result. A voltage this large can damage equipment and cause serious injury to the operator.

At this point all switches should have been closed. Open switch B to remove the D. C. machine from the line. The A. C. machine is now running as a synchronous motor. To stop the motor, open the A. C. line switch F, and when the motor has stopped rotating, open switch C. When F is opened, be careful not to contact the switch terminals, because the D. C. field is still energized and will induce

considerable voltage in the stator until the motor stops completely.

Report: Plot power factor against KW output from the data obtained in Run I.

Plot power factor and line current against field current from the data obtained in Run II.

In calculating the KW output of the motor from the data taken in the experiment, assume the loss of both machines are equal.

Compare the characteristics of the synchronous motor with those of the induction motor.

For what uses do the characteristics of the synchronous motor make it best suited?

List the precautions to be taken in the operation of synchronous motors and explain the hazards that these precautions guard against.

Comments:

The principal hazards to be encountered in the performance of this experiment have been covered in the experiment text. Some of them are brief, however, and can be further explained by the instructor in the discussion period.

The last run which covered the starting of a synchronous motor by driving it with an outside source, also gave some of the problems to be encountered in the parallel operation of alternators. This might also be brought out in the discussion period, particularly the danger of closing the line switch when the machines are not in phase.

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